

Hand Strength and Dexterity Enhancer



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EXECUTIVE SUMMARY

Good Grips created the hand strength and dexterity enhancer project to meet the challenge presented by Bill Phelps. He has Inclusion Body Myositis (IBM), an inflammatory muscle disease characterized by progressive muscle weakness and atrophy. Bill has limited strength in both hands and lost the ability to bend his fingers, making it difficult to grip anything. He needed a device that would help with everyday tasks such as writing, lifting, and holding various objects.

Our team consists of four engineering students attending Cal Poly, San Luis Obispo. We researched, designed, manufactured, and tested a device that would fulfill the problem requirements for three quarters. Our device consists of two main components: a pair of custom gloves and a fanny pack that houses our electrical control system.

1 INTRODUCTION

1.1 Sponsor Background and Needs

Our sponsor, Bill, has Inclusion Body Myositis (IBM), a disabling inflammatory muscular disease that causes progressive muscle weakness [1]. IBM causes muscle inflammation, weakness, and atrophy [2]. The cause of this disease is unclear, but an autoimmune response causes the body's immune system to attack its muscles, thus causing damage to the muscular tissue and leading to decreased size and strength [1]. Currently, there is no cure, but people with IBM can manage it by optimizing muscle strength and function through exercises and assistive devices [2].

Since his 2005 diagnosis, Bill has lost most of the strength in his legs, wrists, and hands and will continue to lose mobility as the disease progresses. He can only control his index finger and thumb on both hands, so he cannot create a fist. Additionally, his wrists cannot sustain any weight over a couple of pounds. As a result, Bill has no grip strength and cannot hold most objects he uses daily, such as a pen, toothbrush, fork, etc. Creating a device that could allow Bill to grip and carry these objects would improve his quality of life and help him complete tasks independently.

Bill is the primary stakeholder for this project. Other stakeholders included the following: the Good Grips team members, Karla Carichner, Dr. Lily Laiho, and Bill's current and future caretakers.

1.2 Formal Problem Definition

Good Grips has been tasked with making a functional device that helps our sponsor, Bill, use his hands more effectively. Our team worked together to create the best solution to meet the customer requirements and engineering specifications discussed in the later sections of this report.

1.3 Objective and Specification Development

We created a device for Bill that can help him grip small everyday household items such as silverware, a pen/pencil, a glass, a remote, a mug, and a cooking pan with minimal effort. The device is lightweight and gives him strength and control over eight fingers. Due to the nature of his condition, we wanted to ensure that the device would support Bill if control over his index finger and thumb worsened. In addition, Bill has a history of falling, and the apparatus needed not to injure or scratch him if he fell. Another important consideration was that our design would not allow the left pinky finger to bend further than 90 degrees as Bill experiences pain in that finger if it bends past this point. He also frequently uses his iPad during the day, which means we needed to leave his index finger uncovered or the device required touch screen compliance.

In addition, some customer preferences were desired but not required. We will refer to these as "wants." These included expanding the list of items he can hold to a heavier weight class, such as bags of sugar and flour, or things that require more control over his fingers, such as squeezing toothpaste out of a tube or opening a jar. Since Bill lives primarily on his own and enjoys

independence, it would have been convenient if he could put on the device himself and potentially wear it in the shower.

For the complete breakdown of customer requirements and engineering specifications, see Appendix B.

1.4 Applicable Standards

While generating our design, we considered the following constraints. The design needed to adhere to any government standards or regulations that might restrict the device, though we did not identify any such restrictions. Bill resides in Park City, Utah, so the equipment had to be transportable. It had to be manufactured at a reasonable cost to adhere to budget requirements. We also ensured that our design would not infringe upon any existing patents, though no patents exist for the predicate devices we used for inspiration.

1.5 Formal Engineering Requirements

Table 1. Formal Engineering Design Requirements

Formal Engineering Requirements					
Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Device Weight Limit	2 Lbs. Per Hand	MAX	M	A, T
2	Finger Control	Helps Control All 5 Fingers on Both Hands (10 Fingers)	MIN	M	A, T, I
3	Grip Strength	2.5 Lbs.	MIN	H	A, T
4	Hold Items of a Certain Diameter with One Hand	0.25" - 4.5"	RANGE	H	A, T
5	Touch Screen Compliant	Pass	N/A	L	A, T, I
6	Allow User to Put on Device with One Hand	Pass	N/A	M	T, I
7	Number of Steps Required to Put on	6 Steps	MAX	M	T, I
8	Bending of Left Pinky Finger	90 deg	MAX	M	A, T, I
9	Comfort	Pass	N/A	L	A, T, I
10	Range of Motion for Each Finger (Except Left Pinky)	90° Per Finger Segment	MIN	H	A, T, I
11	Hand Washable	Pass	N/A	L	T, I

* Green colored cells represent needs; uncolored cells represent wants

* Risk Symbols: High (H), Medium (M), Low (L)

* Compliance Symbols: Analysis (A), Test (T), Similarity to Existing Designs (S), Inspection (I)

The engineering requirements listed in Table 1 require additional information for clarity. We will discuss in-depth details for the requirements below in the order that they appear in Table 1.

Spec. 1: The device must not exceed the specified device weight to ensure comfort for prolonged wear. We measured this first requirement with a standard scale.

Spec. 2: Bill desired a device for both hands (10 fingers). While he still has some control over his thumb and index finger on his right and left hands, we wanted to ensure that our design would account for all fingers if he lost additional function with time. We visually identified that our device caused a displacement in all 10 of his fingers. Though Bill received a device for each hand, we intended for him to use only one hand at a time.

Spec. 3: Because Bill lost the majority of strength in his fingers, our device needed to induce a grip on its own. He needs to carry small items such as silverware, a pen or pencil, a glass, a mug, a remote, and a cooking pan. Holding additional items such as a bag of flour or sugar was considered a want for this requirement. We ensured that we met this requirement by using a hand dynamometer to measure the grip strength with the device. Before sending the device to Bill, we conducted this test, as he did not have access to a dynamometer. We also used the device to pick up everyday household items of known weight and observed how well the device functioned under various loads.

Spec. 4: In addition to the weight support requirement, defining the size of the objects Bill could encounter with the device was an essential but complex requirement to specify. Since items come in different shapes and sizes, we generalized everyday items with a diameter measurement to create a target range for Spec. 4. Our device needed to allow him to hold items between 0.25" and 4.5" in diameter at a minimum. Like how we tested the grip strength in our device, we first tested the device ourselves by picking up items of different shapes and sizes.

Spec. 5: As part of his day-to-day activities, Bill enjoys listening to music on his iPad. Our design must allow him to continue using his iPad. Because the touch screen on the iPad relies on electricity from the fingertip, we needed to keep the index finger uncovered at least 0.75". An alternative to keeping the finger uncovered was to use a conductive material on the index fingertip of our device to ensure that the touch screen feature of the iPad would still function while he was wearing the device. If our design allowed, we wanted to incorporate touch screen compliance for all fingers.

Spec. 6: The device encompasses Bill's hand, which requires the use of the other hand to put it on. Bill lives mostly on his own and enjoys independence, so it was ideal if the device was not only easy to put on but that he was able to put it on by himself when necessary. This specification was evaluated by inspection and by testing the design ourselves.

Spec. 7: As mentioned above, we wanted Bill to put on the device himself. To ensure simplicity when putting on the device, we tried to limit the number of steps that Bill had to put the device on. We tested this specification by counting the number of individual motions required to put on the apparatus.

Spec. 8: Bill experiences pain in his left pinky finger when it is bent past 90°. Our team wanted to ensure the device did not cause him any additional pain. We measured the final maximum angle the device causes the pinky finger to bend and verified that it was below 90° in both joints of the pinky.

Spec. 9: Bill currently has support devices that help him walk, such as arm crutches, but they tend to scratch his arms when he falls. We wanted to ensure that the gadget we supplied Bill was comfortable enough for daily use and would not injure or irritate his hands/arms further if he were

to fall. We intended for the device to be worn for prolonged hours during the day and wanted to ensure that it is comfortable enough to wear for more extended periods. Additionally, the device should be comfortable to wear in conjunction with his other support devices, such as his wheelchair and arm crutches. We tested this by trying on the device and then having others try on the device. Everyone reported the comfort they experienced. We aimed to get positive responses from everyone we asked, and if they were not, we made changes to correct them.

Spec. 10: Bill will use the device to perform a variety of tasks. We wanted to incorporate a range of motion for each finger to allow him to perform these tasks. We analyzed and inspected the degrees of freedom of each finger/group of fingers and ensured that the range of motion for each of these segments allowed Bill to perform desired activities.

Spec. 11: Since the device will contact most of his hand, he needs to clean it. This criterion will ensure it will not cause a rash, smell, buildup of bacteria, or discomfort when subjected to factors such as water, sweat, or dirt.

1.6 Project Management

The team met during class every Tuesday/Thursday from 12:00 - 3:00 PM. We also met outside of class as needed at designated meeting times compatible with all members' schedules, which we defined at the beginning of each quarter (Ex. Spring Quarter: W/F 1:00 PM - 4:00 PM, Sa/Su as needed). The team dedicated 6 hours of classroom time and an average of 2-4 hours of personal time to the project every week during the fall and winter quarters. We spent significantly more hours outside of class during the Spring quarter, closer to 15 hours or more per week.

Each member of the team took on an equal share of responsibility. Open communication of responsibilities, progress, and concerns was encouraged to avoid an uneven distribution of workload. We defined several specific duties. Julia Denison was responsible for communication with the customer and other stakeholders, acting as the team's primary point of contact. All members brought any intra-team conflicts to the attention of Autumn Rexford, who headed conflict resolution. When applicable, the team would refer to the signed Team Contract and the terms defined at the beginning of the project.

There were significant milestones to be completed along the project journey. We created a Gantt chart to show a detailed schedule of milestones and their completion dates. The Gantt chart is in Appendix D.

2 BACKGROUND

2.1 Existing Products

One previous solution to assist grip ability is Active Hands. According to their website, Active Hands is a product made for weak grip or poor hand function. [3] Active Hands products allow the user to put the glove on without help from another person. Their solution to helping people grip and hold items is a glove that utilizes Velcro to attach items into the user's hand and attach their fingers to the item (see images below). The product comes with attachments to hold different items, as seen with the pen in Figure 1 below. Active Hands advertises to help people grab hand weights and exercise gear if they do not have a firm enough grip to do so otherwise. They also branch out to smaller items like silverware, writing/art supplies, and toothbrushes.



Figure 1. Active Hands Design and Use

Another more straightforward solution used in the past is a small 3-D printed set of handles that attach to various utensils, specifically silverware [4]. As shown in Figure 2, the handles have two curved sections that slide in between the user's fingers, allowing them to hold the handle without using any grip strength. The tool is attached to the handle through the use of rubber bands [4]. Users can adjust the sizing of the handle to fit their palms and fingers to help them best hold onto the device.

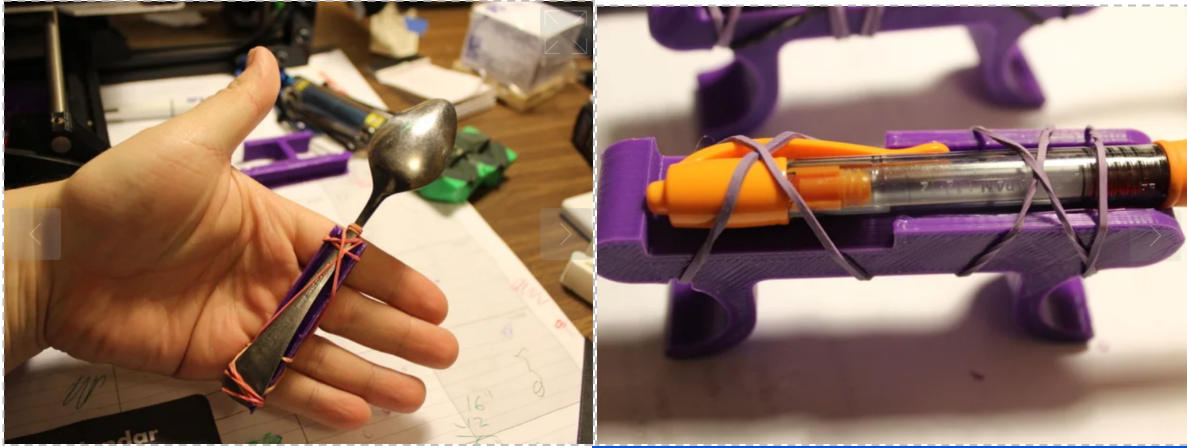


Figure 2. Adaptive Silverware Handles Design and Use

An intermediate solution comes in the form of a purely mechanical design. Several exoskeletal hand prototypes rely on the motion of the wrist and the decreasing distance between the top of the forearm and knuckles as the wrist flicks upwards. One design, 'Spiderhand,' created by a Lehigh University student, uses two links to utilize the effects of this movement [6]. As shown in Figure 3 below, because the length of the metal rod remains the same, as the wrist moves up and the space between the arm and knuckles decreases, the rod will push into the adjacent link and curl the fingers over [6].

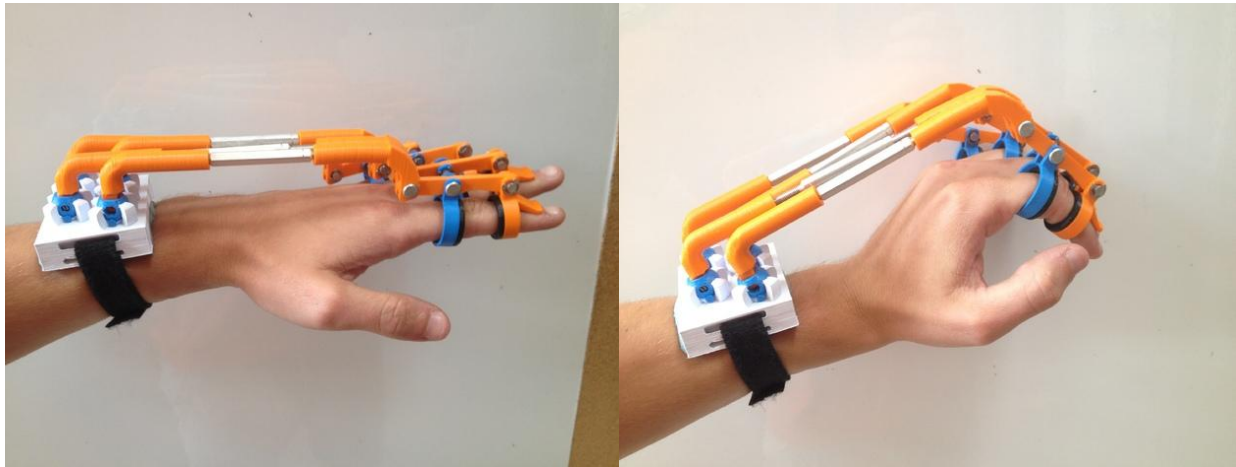


Figure 3. 3D Printed 'Spiderhand'

A curved beam, such as shown in Figure 4, can capitalize on this same wrist movement. As the wrist bends, one end of the curved rod is free to move within a slot, pushing the fingers over as the wrist moves down [7]. The drawback to these designs is that they rely on wrist strength and movement to activate the effect. As the disease progresses, IBM can cause a loss of muscle in the wrist [1], which would eventually render the design ineffective in Bill's case.

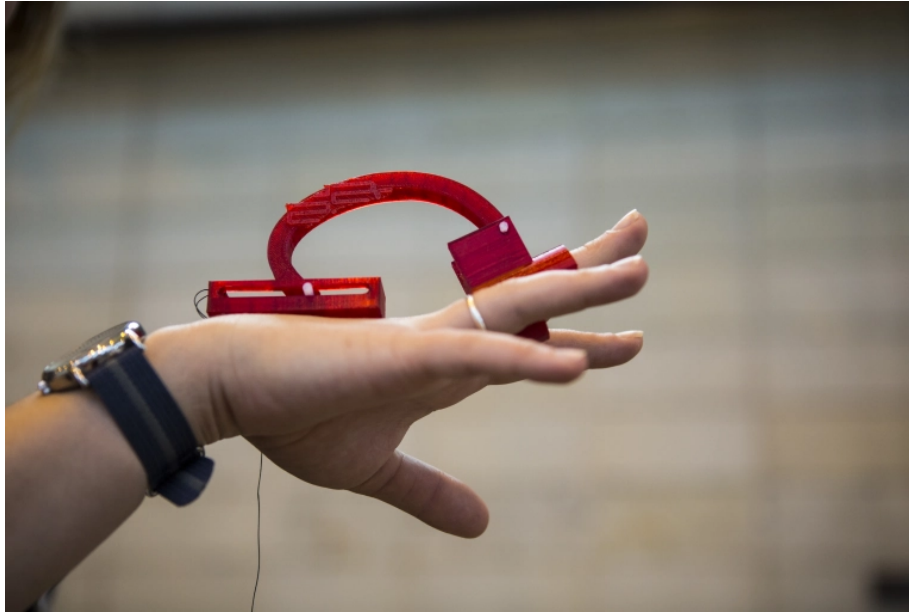


Figure 4. 3D Printed Exoskeleton

2.2 Current State of the Art

One of the more complex solutions to assist people with IBM and other degenerative muscle diseases is an electrical hand exoskeleton called the Flexo-glove. This device is highly portable so that users can wear it throughout their daily activities outside of a hospital or clinic. This particular design consists of two main parts: a flexible 3D-printed glove and an actuation/control unit (ACU) [5]. The glove acts as an interface between the actuating fingers and the ACU, and it is also the cable guide for the flexion and extension of the fingers. The flexible material of the glove can account for the variation in user finger size. The ACU contains two control modes. One mode acts as an intention-sensing via the sEMG control unit, and the other mode works with externally directed stimulation from a smartphone application via Bluetooth [5]. The Flexo-glove design allows for a wide variety of grip styles, enabling the user to grip many different types of objects, as shown in Figure 5 below. Overall, the Flexo-glove provides a 22N (4.95lbf) pinch force, 48N (10.79lbf) grasp force, and object grasp size of up to 81mm (3.19in) and has a total weight of 330g (0.73lb) including the battery [5].

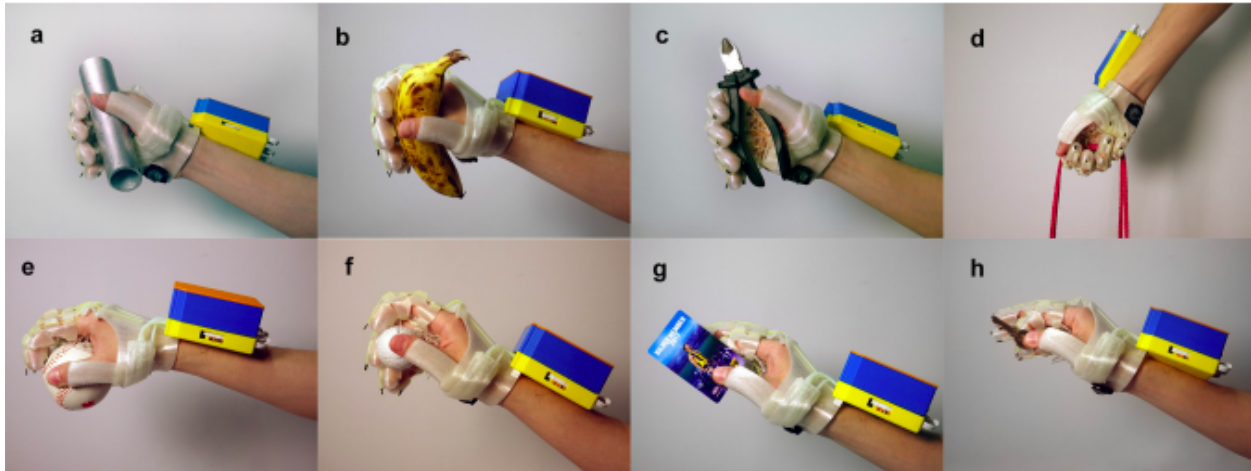


Figure 5. Flexo-Glove Design and Various Grip Styles

Based on the previous solutions designed to improve grip strength and agility in people who suffer from muscle degeneration, we could have taken several approaches with our design. One possible direction could have been to design a type of glove with changeable attachments for different objects and utensils that Bill uses daily. This design would allow him to use many tools without needing to grip them himself. However, it would limit him to tools for which we created attachments. Another possible direction we could have gone is making something similar to Active Hands, where he could wear a glove and attach various utensils. However, instead of having the device cover all of his fingers, we would design it to allow for individual movement of each finger.

Similarly, we could have created a design that mimicked one of the mechanical or electrical exoskeleton solutions utilized in the past. These designs would allow for individual finger movement and various grip styles that could be used for a broad range of objects, as they do not require any specific tool attachments.

3 DESIGN DEVELOPMENT

3.1 Discussion of Conceptual Designs

We brainstormed a wide array of designs and grouped them into concept categories. We will discuss some of the top concepts we considered.

String Based

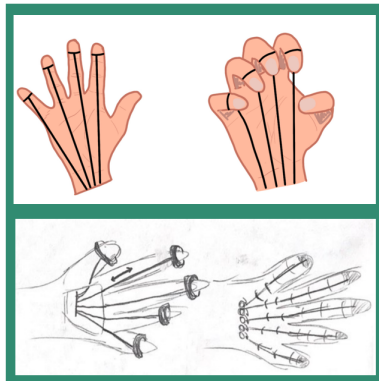


Figure 6. String Based Designs

Description: One of our top concepts was a cable/wire-based idea that would tighten or loosen cables connected to the fingers to open and close Bill's hand. We had multiple versions of this design, and some pulled the lines by unique methods. Such methods include a twisting knob that would tighten the cables, a series of bracelets at different locations along the forearm that the strings could attach to, and a mechanically controlled spool that would simultaneously draw all the cables and more.

How we came up with this design: We saw several designs that controlled the hand with an external exoskeleton, but not many utilize the inside of the hand. We considered how we might involve the inner hand and possibly design a device that would not be as bulky or heavy. After conceptualizing the cable design, we created a quick prototype to prove that the cables would

tighten the hand as much as needed for Bill to use everyday objects. The strings adequately drew the fingers in, and the design felt simple and less intrusive than some of the other prototypes.

Switchable Pieces



Figure 7. Swappable Component Designs

Description: The driving idea behind the swappable component design was that Bill's fingers naturally extend outwards, and the trouble with grip arises when he tries to contain his hand in a tightened position. This design would maintain his hand at a fixed position without blocking the inside of his hand, which would hinder him from holding an item. There would be the main piece on the back of his hand that he would wear all the time and switchable pieces to keep his fingers in different positions for different purposes. This gadget would also keep the inside of his hand largely uncovered so the natural grip of his hand would remain the same.

How we came up with this design: We came up with the idea by discussing how we could create something similar to Active Hands while rendering more hand positions than a cylindrical grip. One concern with this design was that once one hand is locked in a particular place, it would be difficult for him to put another

attachment on his other hand. Therefore, with this design, he could most likely only use one hand at a time. Additionally, the gadget would require customized attachments for each household object, and Bill would be responsible for keeping track of each component.

Exoskeleton Based

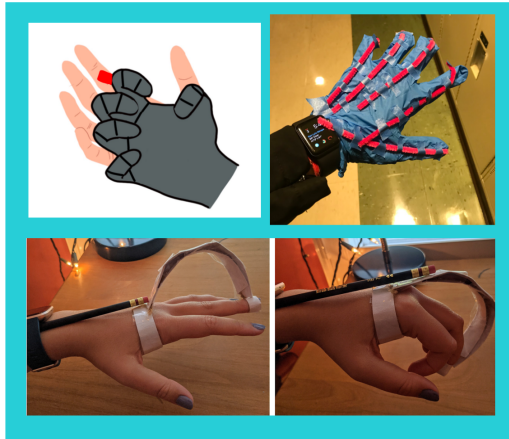


Figure 8. Exoskeleton Designs

involved and have a more significant learning curve than many of our other designs.

Description: We had multiple exoskeleton-based designs, resting outside his hand and constructed of hard material. One method (lower two photos) was very similar to the 3D printed exoskeleton of Figure 4 from our background research. Another (top right) utilizes technology identical to flexible tripods that can be molded into different forms and remain fixed in place. The top-left image is a design that would add a robotic hand to the front of Bill's hand, which he could open and close with the press of a button.

How we came up with this design: Our background research inspired many of these exoskeleton-type ideas. We found existing ideas and considered how we could adjust them to fit Bill's needs. These designs were a bit more intrusive, and we expected they would be more

Attachment Ideas

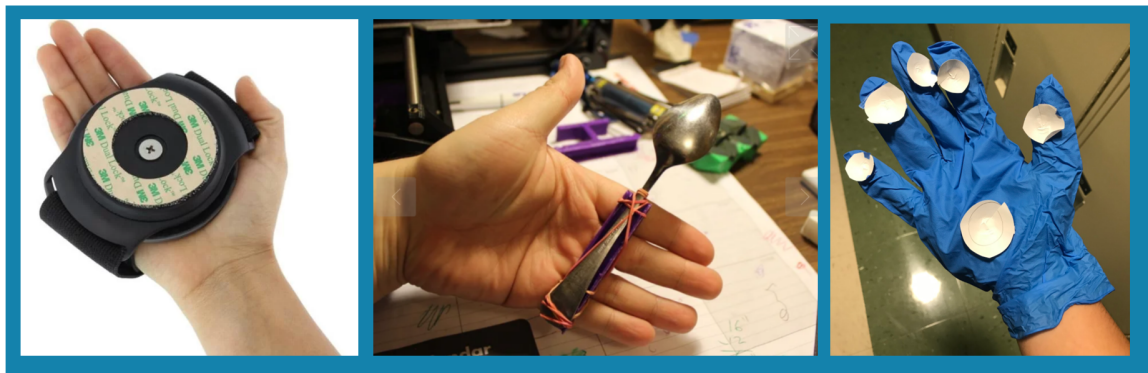


Figure 9. Attachment Designs

Description: The attachment category comprises designs that place mating components on Bill's hand and on the items he uses. The leftmost image shows a product we researched that assists people in holding their iPads. We would adjust this idea to help grasp an iPad and many other everyday items. It works by connecting a sticky film (or magnetic piece, or jig piece) to his hand and the everyday objects he wants to use. Combining the two would be very simple. The middle image shown is from our background research, and it displays a tool to help hold silverware and pens without the need to shut the hand. We considered using this design for silverware, writing utensils, and a toothbrush and designing a similar item that would help Bill hold glasses and mugs without tightening his hand. The right image shows a glove that utilizes suction cups to attach to things. Other ideas included placing a universal attachment to his palm and placing mating pieces on everyday objects similar to GoPro mounts.

How we came up with this design: We came up with these designs because we wanted to branch outside the idea of a glove or device that helps his hand tighten and instead think about how we could help Bill hold items without him needing to close his hand. His fingers could remain in their resting position, but he would still be able to lift things. There were more variations of designs like these, many of which would involve attaching something to his everyday household items that would lock into what he had on his hand.

Snappy Bracelet

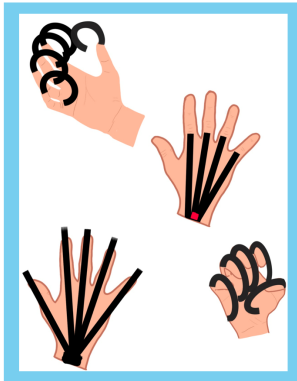


Figure 10. Snappy Bracelet Design

Description: This idea involved using "snappy bracelets." These childhood toys snap closed when hit against an item but can then flattened out again. The concept was that we would attach thin, robust metal strips with a non-slip coating to Bill's hand, and they could be extended out, touched to an object, and closed around that object. If placed on the back of the hand, they would bring Bill's fingers with them. If placed on the inside of the hand, they could potentially act alone. When not in use, they could be flattened and retracted and would have some component to keep them flat.

How we came up with this design: We brainstormed any possible way to help bring in Bill's fingers around an object, and snappy bracelets came to mind as an item that can close on command without electrical components. This idea would require prototyping to ensure the bracelets could be made to the correct size, would not be too forceful, and could carry sufficient weight.

3.2 Concept Selection

After completing our design generation, we compared our solutions in a Pugh Matrix, as seen in Figure 11. Each design was ranked based on the chosen datum, an existing product found in our background research. The two existing solutions we found to be the most promising were Active Hands and Flexo-Glove. Because Active Hands is currently available for purchase and Flexo-Glove is not, we chose Active Hands as our datum. This choice ensured our final design would perform better than an existing solution that one could easily purchase. We gave each of our preliminary designs a rank based on whether it met a requirement better than the datum (+), worse than the datum (-), or the same as the datum (S). After we ranked all of the designs, we calculated totals for each rank per design and compared them.

Design 6 was quickly removed from consideration, as we felt the design was out of the scope of our capabilities and thus would be too difficult to complete in the given timeframe. The matrix highlighted a few stand-out designs, including Design 2, Design 5, and Design 8. We did not move forward with the exoskeleton-based Designs 5 and 8 because they seemed more intrusive and would be challenging to navigate. We also thought they could not be used on both hands simultaneously since when one hand fixes into place, it would be hard to maneuver the other hand into the correct position. We chose Design 2 as our final concept since it was more straightforward and less intrusive than other options while still allowing Bill to grip and hold the same objects. Design 2 is also more lightweight than the others, and there were no negative rankings associated with it.


Concept											
											
Notes	* Active Hands Datum	* not including how strings are attached at wrist				*our altered version of flexoglove					go-pro attachment, velcro/magnet/clip-in between object and palm of hand
	1	2	3	4	5	6	7	8	9	10	11
Criteria	A: Something for both hands	D	S	S	S	S	S	S	-	S	S
	B: Help him hold silverware	A	S	-	S	+	+	-	+	+	-
	C: pen/pencil	T	S	-	S	+	+	-	+	+	S
	D: glass	U	+	+	+	S	+	+	+	-	S
	E: mug	M	+	+	S	S	+	+	+	-	S
	F: remote		+	+	+	+	+	+	+	+	+
	G: pan	D	S	S	S	S	+	-	S	S	+
	H: lightweight	A	+	-	S	S	-	S	-	-	S
	I: Won't injure him if he falls	T	S	-	-	S	-	S	-	-	-
	J: Still helpful if condition worsens	U	+	+	S	S	+	-	S	+	S
	K: can use index finger on iPad	M	+	S	+	+	+	+	+	+	+
	L: avoid pain in left pinky		+	+	+	+	+	+	+	+	+
Total (+)			7	5	4	5	9	5	7	6	5
Total (-)			0	4	1	0	2	4	2	5	0
Total (s)			5	3	7	7	1	3	3	1	7

Figure 11. Pugh Matrix for Concept Selection

Moving forward with this design, we needed to determine precisely how we would pull in the cables. We used another Pugh matrix (Figure 12) to decide between plans, electrically-based and purely mechanical. Similar to the Pugh matrix of Figure 11, we gave each design a rank based on how well it met a requirement compared to the datum, better (+), worse (-), or the same (S). After we ranked all the designs, we calculated totals for each rank per design and compared them. The datum for the electrical versus mechanical Pugh matrix was determined to be the bracelet design because it was the simplest out of the three and easily comparable in terms of function.

The far-right design in the Pugh matrix refers to the electrical method. Upon pressing a button, spools would begin to turn, shortening the length of the cables and drawing the fingers into a fist. The middle and far-left designs of the Pugh matrix show the purely mechanical options. The center design utilizes a knob that would manually turn, providing a similar action to the electrical design to shorten the cables and close the hand. The far-left design consists of bracelets or hooks located at different locations along the arm or body upon which the wires could latch. Each pinpoint would close the fingers to varying degrees, which would depend on the size of the object chosen to grip. The hooks or knobs used for the purely mechanical option would need to be sufficiently sized and adapted to allow Bill to adjust them easily, given his current range of motion.

Analysis of the Pugh matrix determined that incorporating an electrical design will allow him to hold a broader range of items and quickly retract the cables with a button press. As his condition worsens, he may become unable to perform the tasks necessary to adjust the strings mechanically. Moving forward with the electrical design, we re-analyzed the safety risks and additional costs of incorporating electronics in our design.


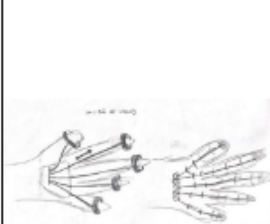

		Mechanical - Bracelets	Mechanical - Turn Knob	Electrical - spools turn and collect wire
	Images			
		1	2	3
Criteria	A: Something for both hands	D	S	S
	B: Help him hold silverware	A	-	+
	C: pen/pencil	T	-	+
	D: glass	U	S	+
	E: mug	M	S	+
	F: remote		S	S
	G: pan	D	S	+
	H: lightweight	A	S	-
	I: Won't injure him if he falls	T	S	-
	J: Still helpful if condition worsens	U	S	+
	K: can use index finger on iPad	M	S	S
	L: avoid pain in left pinky		-	S
	M: simplicity of design	D	S	-
	N: ease of maintenance	A	S	-
	O: easy to use	T	S	+
	Total (+)		0	7
	Total (-)		3	4
	Total (s)		12	4

Figure 12. Pugh Matrix for Mechanical vs. Electrical Design

3.3 Supporting Preliminary Analysis

When the cable design spawned during concept generation, we made a very simple prototype to test the idea. We needed to test how far the cables could pull the fingers in. To do this, we created rings out of cardboard and used string as the cable element. We only tested the index finger, but this alone showed that the cable brought the index finger into a tight enough grip to hold the items Bill most commonly uses. This idea mimics the flexor digitorum profundus and flexor digitorum superficialis tendons in the fingers. These tendons help bend the fingers from the fingertip joint and glide in sheaths down the fingers to the wrist.

3.4 Proof of Concept Analysis and Testing

We needed to conduct a more thorough concept test to verify that the cable concept could activate all five fingers simultaneously without any unforeseen issues. This test represents the first test from our Design Verification Plan, detailed further in our Test Descriptions section. For this test, we pulled all five cables simultaneously to verify that they would pull the fingers down synchronously and create an influential grip position (see Figure 13 below). We found that the cable concept does provide a functional grip.

We discovered that the thumb cable does not pull the thumb into an advantageous position. It draws the thumb towards the side of the hand rather than the front. The rightmost image of Figure 13 depicts this motion. The thumb must move towards the front of the hand and oppose the force of the fingers to grip an object successfully. We decided to use the spools to pull in the fingers but needed another way to position the thumb in place, possibly just a rigid thumb brace or a strap. We were also able to test and compare material options for several components. Fishing wire proved to be the ideal cable material, compared to other types of string, as it creates low resistance between the glove and other materials, has high strength, and stays in place well. We also tested two hard ring materials: polymer clay and resin. Polymer clay was ideal for prototyping because we could size the rings as needed, but it is not durable enough for the final design. We also found that resin is not ideal for our final ring material because it becomes malleable as it warms from sitting against the hand. In later prototyping stages, we found the hard rings too uncomfortable for long periods. We realized that we could instead make rings out of softer material. Still, overall, this test gave us essential information for moving forward with our detailed design development and material selection. Most importantly, this test proved that we could successfully use the most crucial mechanics from our design to complete our goal.



Figure 13. General Cable Concept Test

Since we were unable to work with Bill physically, we sent him a kit (Alja-Safe Lifecasting Starter Kit) to create molds of his hands to mail back to us. These molds were exact replicas of Bill's hands, shown in Figure 14, and we used them during the final prototyping and manufacturing stages to ensure all components of the gloves would fit his hands. Using the molds allowed us to test the sizing and fit of all elements without continually sending parts back and forth between Bill and us, considerably cutting down production time.



Figure 14. Bill's Hand Molds

4 DESCRIPTION OF FINAL DESIGN

4.1 Overall Design Description

Shown below in Figure 15 is a simplified image of our chosen final design concept. We based it on our cable-driven idea depicted in Design 2 of the Pugh Matrix. It consists of a glove with cables running down each finger, through the palm, and to the wrist. Each finger has a string, and they move through the glove in separate tracks to keep them from tangling with each other or interfering with grip. Soft fabric rings contact each finger segment to keep the string as flush to the hand as possible. The outer material of the glove has extra grip, allowing Bill to have a better hold on objects that he lifts. The cables draw from the wrist area, pulling down on the anchored point at the top of the finger. As the wires pull, the fingers bend and close into a fist. The length of wire that wraps around the spool directly correlates to how far the finger closes.

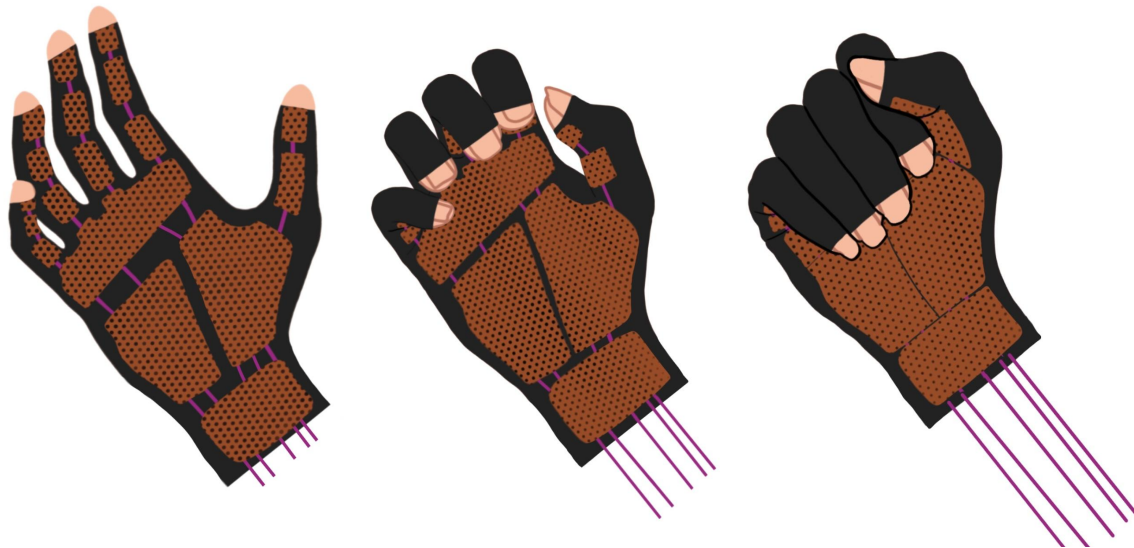


Figure 15. Final Design Concept

The cables pull in with the use of gearmotor-powered spools that they wind around. To reduce the weight of our overall device, we limited the design to two motors per hand. We found that fingers tend to move naturally in subgroups which makes the two-motor method practical. The index and middle fingers pair well together as well as the ring and pinky fingers. After analyzing the force required to bring in the two-finger subgroups (see Table 5 in the Test Descriptions and Specification Verification Checklist section later on in the report), we found it comparable to bringing in each finger individually. Thus, using these subgroups reduces the device's weight and requires less force to bring the fingers in. An Arduino Uno controls the gearmotors and rests in a fanny pack Bill can wear. The fanny pack also contains other electrical components, including a battery and a motor shield for the Arduino. The motor shield makes the battery output current match what the motors require. The gearmotors and spools are attached to the glove at Bill's wrist and wired to the fanny pack.

Overall, this cable-based design meets our requirements well. The use of cables attached to each finger helps control all fingers (minus thumbs) on both hands. The extensive range of the wires allows Bill to hold all of the objects he wants, as the device can be left primarily open for larger objects, such as a mug, and be closed very tightly for smaller objects, such as a pencil or utensil.

The use of electrical components as an actuator allows Bill to use the device with a simple push of a button, which will enable him to use the device as his condition worsens. It also improves the overall user interface.

The device as a whole is very lightweight, constructed from a few reasonably light materials. The flexibility of the materials also makes the gloves comfortable for Bill. The glove tips are largely open so that Bill can use his bare fingertips, making the device touch-screen compatible and allowing Bill to use his iPad and other electronic devices easily.

4.2 Detailed Design Description

Mechanical Components

The gloves started as a pre-existing open-back weightlifting glove, shown below in the component selection section. The gloves had a single layer of rings already incorporated at the base of the fingers, and our design added a second layer of loops to the middle segment of the fingers (see Figure 16 below). We designed the backs of the gloves to be as open as possible to increase ventilation and release as much heat as possible. We constructed finger caps out of nylon material with an open finger pad design, enabling Bill to use his iPad and maintain the grip from his skin. We attached 3M gripping material to these finger caps to add additional friction and grip strength. We attached side rails, also made from nylon, to align the two layers of rings and the finger caps. A hollow-braided fishing wire was secured to the top of the finger caps and fed through polyester string tracks. These tracks sewed onto the inside of the glove from the fingertips to the motor casing. They keep the fishing wire from moving or tangling inside the glove and act as another barrier shielding Bill's skin.

Other components included in our glove design were the backhand strap and the thumb strap. We made the backhand strap from the same neoprene material used throughout the glove. The purpose of this strap is to ensure that the glove follows the contour of Bill's palm when he closes his hand. We encountered issues with bunching at the palm area, decreasing the amount of cavitation that naturally occurs when the hand moves into a closed position. The strap helped increase the palm's available surface area, allowing the fingers to wrap further around an object.



Figure 16. **Left:** Pre-existing weight-lifting glove, **Right:** Modified glove

The thumb uses a purely mechanical design, controlled with an elastic band. The flexible thumb strap shown in Figure 17 is an older iteration of the component, sewn to the thumb ring and free to hooked onto the bottom loop of the ring finger. With this configuration, it was challenging to locate precisely where the strap needed to attach after wrapping it around the item. After testing, we altered the design so that the hook is visible when securing the strap. We sewed the strap to the outside of the ring finger's bottom loop. It stretches around an object in hand and hooks onto a clip on the thumb. During testing, the strap brought the thumb around items in the correct gripping position. It provided confidence in how secure the user felt about holding things in place without slippage. As shown in more detail in Figure 17 below, two different loop sizes are available. The first loop is for smaller items such as a pen or utensils. The outer loop is for larger objects, such as a glass or mug. A pull-tab was connected to the end of the elastic band for easy attachment and release.



Figure 17. Close-up of Thumb Strap

Electrical Components

As the fishing wire comes down the hand, it collects onto spools attached to the gearmotors. The 3D printed casing that encloses the spool and gearmotor connection is attached to the glove on the inner side of the wrist. The four cables (for each finger excluding the thumb) split onto two gearmotors, with the index and middle finger attached to one spool and the ring and pinky fingers attached to the second. Although there are two separate spools and gearmotors, the design spins both motors simultaneously, bringing in and releasing all of the fingers together.

All of the electrical components used for controlling the gearmotors at the wrist were stored in a fanny pack that Bill will wear while using the device. Inside the fanny pack are an Arduino Uno, a motor driver shield with a screw shield attachment, and a rechargeable battery. The motor driver shield lies directly on top of the Arduino Uno. The screw shield attachment is where all of our connections to the buttons occur. This shield ensures reliable and durable links to the buttons and permits easy design changes without re-soldering. The gear motors on the arms are connected directly to the motor shield in the fanny pack through long 12-gauge wires. We implemented a connector piece near the glove that allows Bill to disconnect the glove from the long wire coming out of the fanny pack. This function enables Bill to string the wire through his shirt if he desires and offers a way to wash the glove.

Normally open, single-pole, single-throw (SPST) buttons activate the gearmotors, implemented in the Arduino code. In addition, there is an on/off switch connected to the main power supply in case an emergency stop is necessary while the device is in use (seen below in the SPST toggle in Figure 18). This switch is wired directly to the motor shield and will immediately cut the power if turned off.

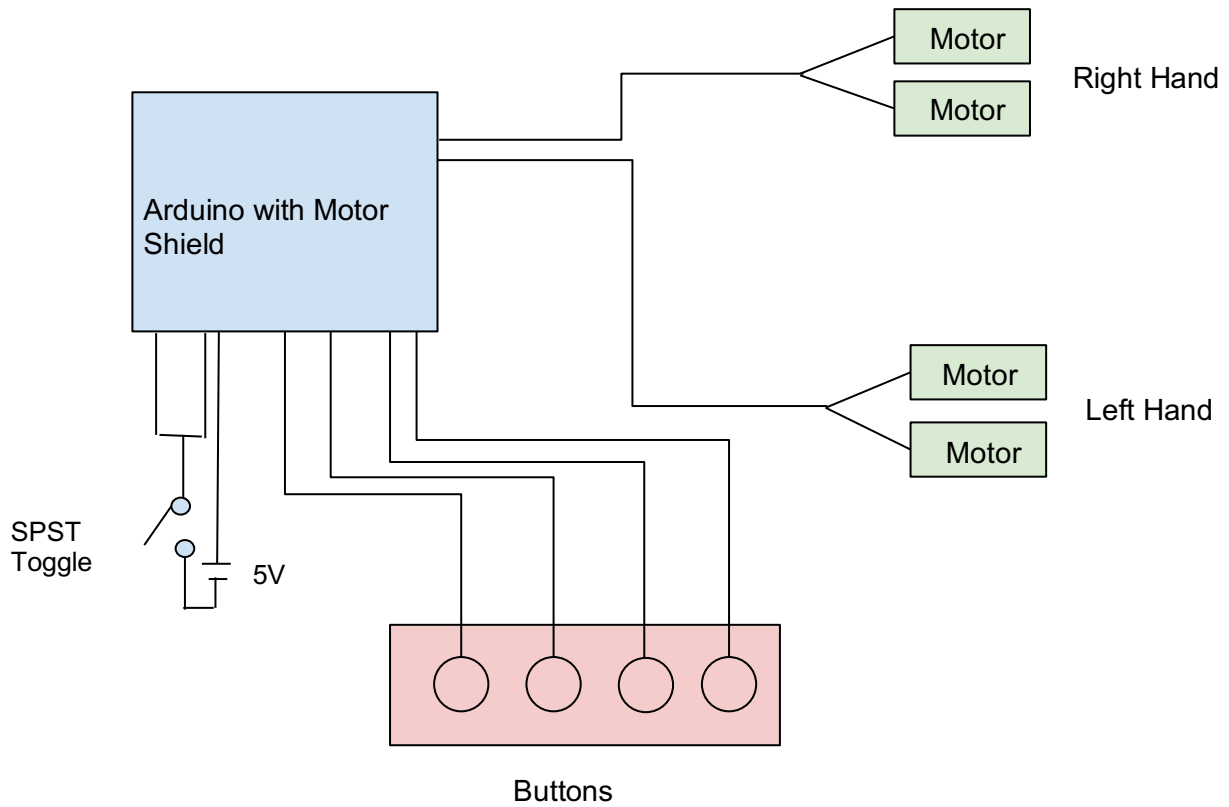


Figure 18. Electrical Component Wiring Diagram

4.3 Cost Breakdown

Table 2 below displays a breakdown of the total cost of \$331.74 for the final design consisting of a pair of gloves and a fanny pack.

Table 2. Final Cost for Design

Device Category	Material	Vendor	Cost
Gloves	Neoprene Weightlifting Gloves	Amazon	\$19.95
	Grip Material	3M	\$23.25
	Elastic Thumb Strap	N/A	N/A
	Nylon Material	Quality Fabrics	\$5.37
	Fishing Wire	Tackle Warehouse	\$24.46
	Velcro	Amazon	\$11.49
	Polyester Blend Tracks	N/A	N/A
	Grommets	Michael's	\$6.99
Electrical Components	Pololu 6V Micro Metal Gear Motors	Pololu	\$63.80
	Arduino Uno	Arduino	\$23.00
	Arduino Motor Shield	Arduino	\$23.00
	Gikfun Screw Shield Expansion Board	Amazon	\$9.28
	Anker 10000 mAh Rechargeable Battery	Amazon	\$29.99
	Electrical Casing	N/A	N/A
	Spools	N/A	N/A
	Fanny Pack	REI	\$32.63
	Plexiglass	Home Depot	\$6.29
	Wiring	Coast Electronics	\$26.89
	Buttons	Coast Electronics	\$25.35
Final Cost			\$331.74

We sourced our materials and supplies from several vendors, keeping cost, quality, and convenience at the forefront of decision-making. Amazon was one of our major vendors, as they carry a wide variety of supplies at competitive prices and quick delivery times. We purchased the initial fishing wire, servo motors, base gloves, rechargeable battery, and screw shield through Amazon, which provided flexibility for design changes during the prototyping stage. For instance, we found the fishing wire originally used to prototype too thick, and within two days, we ordered and obtained wire of a smaller diameter. Similarly, we quickly secured servo motors used for initial feasibility testing to perform additional analysis on motor types following proof of concept.

3M was the vendor of the gripping material used for adding extra grip to the finger caps of the glove. Their gripping material uses microreplication technology, which engages thousands of tiny thermoplastic elastomer stems, or "fingers," that increase control for better gripping performance in dry and wet conditions [10].

We purchased the Arduino Uno and Arduino Motor Shield directly through the Arduino website, and we sourced the gearmotors from Pololu, a well-known supplier of electronics.

We sourced many of our components from local vendors, such as the nylon fabric, fanny pack, and various buttons and electrical wires. Local availability made it much easier to get materials on the spot and compare different material options on-site before purchasing them. We were able to use a personal 3D printer to cut down the lead time for printing our various iterations of spools and motor casings.

4.4 Material, Geometry, and Component Selection

The gripping material used on the outer palm was worthy of attention because it could increase the hand's frictional holding force without increasing tension in the cables. To maximize this frictional coefficient, we considered 3M gripping materials recommended to us by the Senior Functional Apparel Designer at Harvard University, Diana Wagner. She specializes in textiles for soft robotics. This material uses thousands of tiny thermoplastic elastomer fingers to increase the contact area with the object. A 3M representative recommended several products from the gripping material (GM) line that best suit our needs: GM531, GM631, GM731, and 3M GM Work Gloves.

We inspected the materials by tactile feel and conducted an experiment to compare frictional forces (discussed in the Test Descriptions and Specifications Checklist section). The most considerable friction resulted from grip-on-grip contact, and the best grip came from GM631. Thus, along with incorporating the GM631 into our design on the finger caps and using the pre-existing grip on the chosen glove, we encouraged Bill to wrap some of his most commonly used objects in a small amount of the 3M grip tape (GM531, GM631, or GM731) to maximize the capability of the glove.

To choose an outer glove for our final design, we sent Bill three options, and he selected which glove felt most comfortable and supportive.

The first of the three gloves we sent him (seen in Figure 19 below) was the glove that we incorporated into our final design. They are typically weightlifting gloves, so they have built-in wrist support. The wrist support is helpful to prevent Bill's wrists from breaking when picking up objects. In addition, the open-back design allowed the glove to be breathable and more comfortable on his skin while he used the device. The glove secures with a Velcro strap along the wrist. This glove was manageable for Bill, and we watched him put on the gloves over a video call to confirm. We observed that Bill could easily slide his fingers through the rings, making it a suitable choice for our final design. From this qualitative test, we were also able to judge the sizing of the glove on his hand. After observing that the large-sized glove was snug, we increased the size to an extra-large to provide more space for the tracks and additional glove elements. A looser fit also improved overall comfort.



Figure 19. Open Back Weightlifting Gloves

The second pair of gloves we sent to Bill was similar to the first pair seen above. As these are another pair of weightlifting gloves, the wrist support is built-in, and there is additional grip on the palms. The method of attachment remained the same with a Velcro strap along the wrist. The main difference between the two was the open or closed backing on the gloves. Since our design incorporated tracks and cables that run down the finger, there was concern that the open-glove layout would lead to issues with string or track exposure, which is a potential hazard. Since we designed our tracks and cables to run along the inner palm and attach to the rings, both glove options were suitable. For breathability and comfort purposes, we decided to move forward with the open-back glove instead.



Figure 20. Closed Back Weightlifting Gloves

The last type of glove we considered was a fully enclosed glove with a zipper closure. This glove was comfortable and easy for Bill to put on with the single zipper. The closed design of the gloves would have also ensured that the cables would be wholly encased, eliminating any potential hazards with exposed strings to his hand or the environment. However, this glove lacked wrist support, and its closed nature could lead to undesired overheating of the hands.



Figure 21. Zipper Close Gloves

After Bill made a selection, we modified the existing glove to work with our cable design, adding another layer of rings and finger caps to keep the cables secured at the top.

The gloves we chose to alter were made of a neoprene material which was comfortable and flexible. For consistency, we made the second layer of rings from neoprene material. The neoprene had too much stretch for the more rigid components of the glove, including the side rails and the finger caps, so we used nylon for these components. The nylon provides rigidity to

the design, and its edges can be finished quickly with heat. This material helped with the overall structure of the glove, making it easier for Bill to put on and take off the device.

We considered several factors when deciding which electrical components to use for our final design. These factors included weight, price, ease of implementation, holding torque, rotation, and battery usage.

The primary actuators we looked into were stepper motors, hobby micro servos, and gearmotors. After considering the factors and running preliminary tests, we ultimately decided to use gearmotors in our final design.

Stepper motors (see Figure 22) had an equal share of pros and cons. The stepper motor was very accurate as its "steps" were typically in increments of 1.8 degrees. In addition, they require little to no coding since a stepper motor operates in an open control loop. Once a voltage is applied to the stepper motor, it will rotate to the desired position. Stepper motors are also very durable and exhibit a high holding torque. Unfortunately, stepper motors are very heavy and expensive. Since our design would move his fingers in at least two subgroups, we would need multiple stepper motors, which would quickly drive our device cost and weight up.

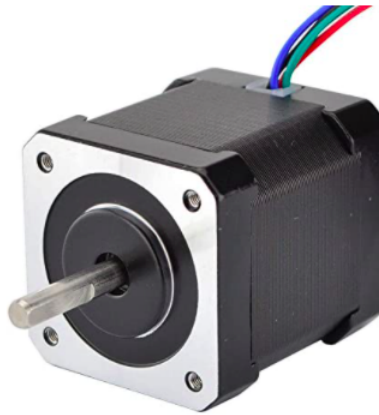


Figure 22. Stepper Motor

Looking over past senior projects such as the "Robotic Fingerspelling Hand" and the "DIY Robotic Hand" from Instructables, we looked into using hobby servos in our final design (see Figure 20). The micro servos are a gear-based mechanism and thus have significantly high holding torque. In addition, these servos weigh substantially less than a stepper motor and function easily with an Arduino. Although the micro servos weigh less, the servo motor is still relatively large. They would have added to the weight and bulkiness of the device on Bill's arm. While servo motors meet many of the desired factors, such as price and ease of implementation, they are not as durable and need replacing more often than stepper motors or gear motors. After testing, we found that the most significant limitation of servo motors is that they can only rotate through 180 degrees. The stepper motor and gear motor both rotate infinitely. The radius of the spool would have to be unrealistically large to obtain the same linear-pull distance within a half-

spin (180 degrees) that a smaller spool could get over multiple spins. The infinite rotation of the stepper and gear motor would allow us to reduce the size of the spools we are using to wind the cables.



Figure 23. Servo Motor

The last type of motor we decided to look at for our final design was a simple gearmotor seen below in Figure 24. These small, brushed DC gearmotors exhibit high holding torque due to the back-drive of the gears holding the position. In addition to being inexpensive, they are much smaller than both the stepper motor and the servo motor, at roughly one-eighth of the size of the servo motor. This micro metal gearmotor permits the spool's infinite rotation, which allows us to downsize the spool used in our final design. The gearmotor has a positive and negative terminal that power and control the direction of the motor. A simple switch of the positive and negative leads would reverse the direction of the gearmotor, allowing the design to bring Bill's fingers in and release them. These gearmotors require the battery to supply significant current to ensure they do not stall or underperform, addressed in the battery and electrical component selection. However, the compact size, infinite rotation, and high holding torque made the gearmotor the best choice for our final device.



Figure 24. Micro Metal Gear Motor

The chosen gear motor required a run current of 100 mA with a max efficiency of 420 mA. Based on these specifications, we incorporated a 5V 10000 mAh portable battery to power our Arduino board connected through a motor driver shield to our gearmotors. The motor shield ensured we were getting enough power to our gearmotors to bring Bill's fingers in and supply sufficient grip. This portable battery can be detached from the device and recharged, which means Bill will not need to buy and change batteries continuously. We expect the battery to last three days under continuous use before it requires a charge. We incorporated an on/off toggle switch to preserve the battery when the device is idle and function as an emergency stop.

Another selection we made for our electrical components was the type of controller implemented in our design. This selection was made based on the layout of our final design and comparing functionality. The two main options for controllers were the Adafruit Trinket M0 and the Arduino UNO seen below in Figure 25 and Figure 26, respectively.

The Adafruit Trinket M0 is a very compact and lightweight controller with a weight of 1.4 g and dimensions of 1" by 0.6". It is interfaceable with Arduino code but has a lower output of 3V instead of the 5V from the Arduino Uno. In addition, it had limited output pins which caused issues when trying to connect our buttons to the controller. The weight and size of the trinket would be ideal if we placed all the electrical components on the arm, but with the adaptation of our fanny pack design, this requirement was not as essential.

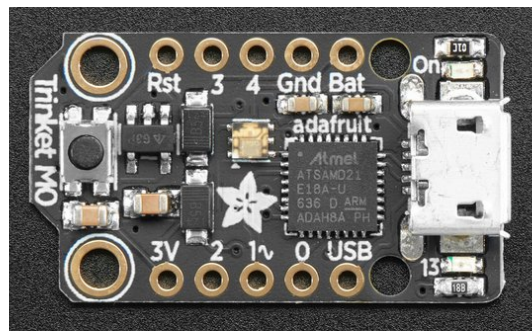


Figure 25. Adafruit Trinket M0

The Arduino Uno with dimensions (2.5" x 2.1") is a much larger and heavier controller than the Adafruit Trinket M0, which is comparable to the size of a quarter. It was used primarily in our testing due to the ease of implementation, the large number of pin-outs, and the addition of easy screw-in connections. With our initial design idea, which had everything on Bill's arm, the Arduino was not a feasible choice due to its bulkiness and weight. After switching our design to place all the electrical components in a fanny pack on Bill's waist, we were not limited by the weight requirement of the controller. Due to the ease of interface with the motor driver shield, Arduino code, and power supply, the Arduino Uno was the best option for our design.

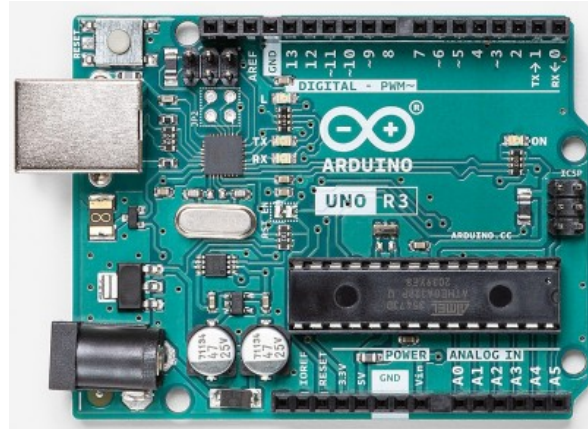


Figure 26. Arduino UNO

4.5 Safety Considerations

Attached in Appendix 3 is a hazard identification checklist that outlines various hazards that could occur with our design. The main risks that needed consideration were avoiding any pressing or pinch points and protecting electrical systems (gear motors, Arduino, and battery). As mentioned in the details of our chosen design, the cables were sewn into tracks and rings on the glove themselves to keep them flush to the fingers. If the rings or tracks were too tight against his finger, they may create uncomfortable pressing or pinch points when Bill uses the device and could potentially reduce blood circulation to these areas. To avoid this, we had Bill send us a mold of his hands to customize the glove.

Our design with electronics incorporated a rechargeable battery, an Arduino with a motor shield, ribbon wires, and two gearmotors to bring in the cables. All the electronic components except the gear motors and wires to the gearmotors were stored in a fanny pack that Bill can wear on his waist. This design kept the electronic components in a single location away from any potential environmental or general damage. We cased the gearmotors that reside on his arm in a 3D printed box that protects them when the glove is hand washed and can help avoid environmental damage such as water or sweat. Heat generation was also a concern, so we took proper care to ensure that the electronics would not overheat by monitoring the current to the gearmotors. In addition, the motor casing was designed with vents on the side to allow for proper heat dissipation to the surroundings without causing discomfort near the skin.

An additional hazard with motors is the point where the cables retract. A dangling object could be pulled in with the strings when the motor is spinning, causing a safety hazard. We addressed this hazard by fully encasing the gearmotors and designing small holes in the casing for the strings to ensure no objects could enter into the motors. The fabric tracks also lead up to the case.

4.6 Maintenance and Repair Considerations

The chosen components in our final design, including the glove, the hollow-braided fishing wire, and the finger caps, are washable. Our design sufficiently cased all electronic components away from the glove so it can be easily hand-washed. In addition, the glove we created for Bill incorporated an open-back, which helps keep the glove breathable while wearing.

We used off-the-shelf products for our battery and gearmotors to simplify electrical component replacement and maintenance, using Amazon and Pololu as our primary vendors. If these products need replacing, we will provide Bill and his caretakers with the item number and instructions on rewiring the gear motors and battery. The gear motors have a simple two-wire system that they could easily re-attach to the Arduino and the battery if necessary.

The mechanical portion of our device can be easily repaired and re-attached to the electrical portion of our device without having to replace the electronics since they are in distinct locations. In addition, when manufacturing our final design, we paid close attention to critical failure points and ensured those items or areas were quickly accessible should they need repair or maintenance in the future.

5 PRODUCT REALIZATION

5.1 Manufacturing Processes

The casing and spools for the gear motors were 3D printed, using both Innovation Sandbox on campus and personal 3D printers. We printed them from polylactic acid (PLA). Due to the small size of the holes on these components, we often drilled out supports with a fingernail drill. We sanded down any rough edges by hand.

A fanny pack holds all of the electrical components other than the motors. The buttons and on/off switch are located on top of the fanny pack. We adjoined a layer of plexiglass above and below the top fabric of the fanny pack to add rigidity and provide a base for the buttons. We took rough measurements of the D-shaped flap and sketched its outline in Adobe Illustrator. Using the specs of the buttons, we added holes where the buttons were to pass through. We used the laser cutter in the Mustang 60 workshop to cut out these shapes in plexiglass. We cut a wood piece of the same size for the bottom of the fanny pack to provide additional shape and stability.

We cut buttonholes through the top of the fanny pack after securing the plexiglass with e-6000 glue and screwed the buttons into place. They were initially red, but two were painted black with nail polish to distinguish them as "open hand" buttons from red "close hand" buttons.

We connected the electrical components using a combination of solder and screw-in terminals. We cut wires to size with a wire cutter/stripper. Following our electrical design, each component was connected and soldered together. We covered any exposed wire junctions with heat-shrink tubing. Wires that lead into the Arduino did not require soldering, as the motor shield provided screw-in terminals. These made connecting and disconnecting the wires extremely simple.

Table 3. Manufacturing Schedule

Manufacturing Task	Completion Date
Send spool and casing parts to Innovation Sandbox	4/29/2021
Program Arduino	5/15/2021
Sew glove components	5/24/2021
Final assembly	5/25/2021
Mail gloves to Bill for testing	6/10/2021

Our motor and spool casing went through several revisions before reaching our final design. Figure 27 shows an image of our final design. On the left is an exploded view of the assembly showing the motor and spool inside, and on the right is the closed assembly. Our final design was composed of three pieces. The bottom piece of the casing was sized around the motors and

spools. On one side, it has holes for the motors' wires to come out (bottom right image). On the other side, it has four holes for the cables and two for the spools' rods (top right image). The rods hold the spools on a central axis. The base has tightly tolerated walls around the spools, which prevent the cables from shifting around and keep them in a correct position around the spool. The purpose of the middle layer is to level out the top surface. The air holes of the middle and top layers help to dissipate any heat the motors might create. The top layer also includes holes for the rods that redirect the cables around the spools. The interior rods can be seen in our final assembly images in Figure 32. All three components screw together on the corners of the case. SolidWorks drawings of each of these components can be seen in Appendix I. The SolidWorks drawing for the spools can be found in Appendix J.

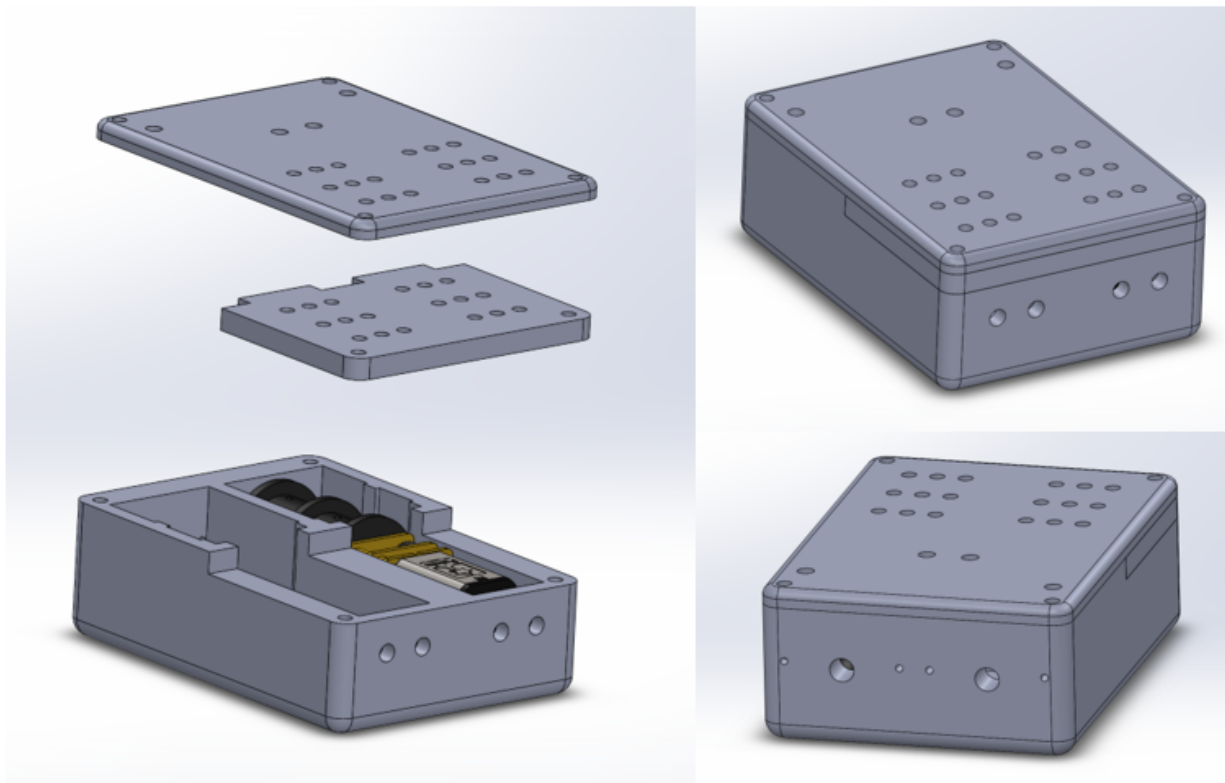


Figure 27. Final Motor and Spool Casing SolidWorks

5.2 Glove Construction

We made the gloves to custom-fit Bill based on plaster molds of his hands. We started with a base glove, the Fit Active Sports weightlifting gloves, and made heavy modifications. Both gloves were manufactured with a sewing machine, hand stitches, e-6000 glue, and super glue. Helpful tools included a seam ripper, sewing clips, pins, tailor's chalk, fabric scissors, a rotary cutter, cutting board, a thimble, and pliers. The sewing machine we used is a Brother XR3340.



Figure 28. Final Glove

The soft ring segments, wrist strap, and back-hand strap are of neoprene. The finger caps are made of 600 Denier Nylon with a Polyurethane coating. The palm portion of the glove is a thin foam pad with a high-grip material sewn onto the exterior. The cable tracks are a polyester blend knit. All edges, except the back-hand strap and finger caps, are finished with polyester bias tape. The bias adds additional structure to the fabric and prevents any raw edges from fraying.

The unmodified gloves extended too high past the top of the palm. The top portion of bias tape and the strip of neoprene that formed the original finger loops were seam-ripped out. We cut the foam of the palm down about $\frac{3}{4}$ -in.

The strip for the finger loops was too wide for our purposes. They were thinned by cutting out the inner portion of neoprene and gluing the two outer biased edges back together with e-6000. It was secured by passing a zigzag stitch over the two butted edges, catching both sides of the fabric. The middle tier of rings was made by employing this same method on the neoprene strips from a separate pair of gloves.

The bottom tiers of rings were sized based on the molds of Bill's hands. An example of how we used them is shown in Figure 28. They were pinned and basted in place around the finger molds. They were secured down by passing a straight stitch back and forth with the sewing machine.

Fabric tubes, which can be seen on the glove in Figure 28, were straight-stitched at a $\frac{1}{4}$ -in with a $\frac{1}{8}$ -in seam allowance and flipped inside out to form a tube. They act as tracks for the cables to hold them in line, prevent tangling, and avoid rubbing against the skin. They were hand-stitched onto each tier of rings and along the inner palm. The tracks run from the tips of the fingers down to the motor casing on the lower wrist. When the tracks meet the bottom of the palm, they pass through $\frac{3}{16}$ -in grommets, which flip the cables to the other side of the glove. These grommets were pressed by hand.

The finger caps that anchor the cables at the tips of the fingers were superglued and hand-stitched. Initial measurements of each fingertip were taken from the molds to cut the Nylon strips. Each raw edge of the Nylon was briefly touched with a flame to seal the edge and prevent fraying. The cables are hollow-braided fishing wire. The hollow braid design resembles a Chinese finger trap and allows the wire to be compacted, opening the braid and increasing its width. They could then be sewn directly onto the caps with a zigzag stitch. A Brummel lock was used to create a loop in the wire, and the free tail is spliced back into itself to create a seamless finish. The open-front design of the caps is meant to expose the finger's pad and allow them to maintain their natural grip. 3M Grip tape was cut to size and glued onto the top and base of the caps to add additional grip if they come into contact with objects.

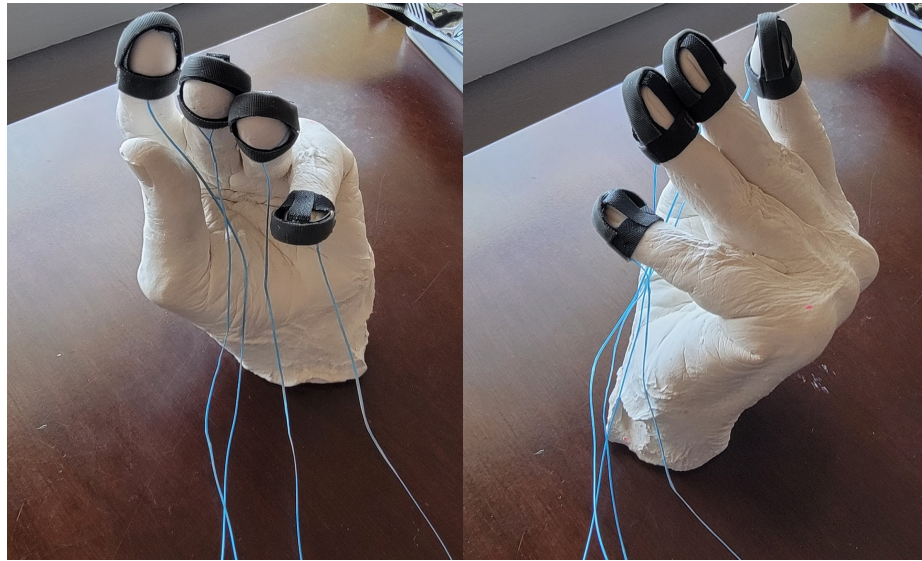


Figure 29. Finger Caps

The back of the glove was left open to increase airflow and reduce heat buildup. A neoprene strap was added to the back to help the foam maintain contact with the palm upon hand closure.

The wrist strap on the original glove needed to be extended to account for the spool and motor casing around which the strap passes. The strap from a separate pair of gloves was used to make this extension possible. The functional locations of the Velcro patches changed, and they had to be seam ripped out and re-stitched in proper spots. The bias tape around the original gloves needed to be seam ripped out, sized, joined, and sewn on again to create a smooth finish.



Figure 30. Glove Finishing Process

Almost the entire glove was finished with bias tape. Although the bias from the original glove was repurposed whenever possible, it was necessary to make additional bias tape for specific glove elements. Similar fabric to the original bias was used to make the glove appear more uniform. The flexible fabric had difficulty forming a crease when pressed with an iron, so several methods were employed to make the tape. A cornstarch concoction was made with starch and water, and this stiffened the fabric enough to hold a crease. Hairspray had a similar influence on the fabric. After treating the fabric, bias tape makers were used to shape and fold a strip of fabric into a double fold bias, pressed into place with an iron. The self-made bias tape and the original bias tape from the glove were challenging to sew into place properly while catching all of the necessary layers. The most effective method was to use Elmer's washable glue to set the fabric in place. This process is shown in Figure 30. The glue was machine-sewn through once dried, guaranteeing that the tape would be caught on both ends with all required layers in between. The Elmer's glue, corn starch paste, and hairspray were all capable of washing away once the entire glove was complete.

After the final construction of the glove itself was complete, the fishing wire was threaded through the tracks and attached to the spools.

5.3 Software Development

The Arduino Uno was a simple microcontroller board that governed our electronics. The Arduino was programmed to close the fingers using two motors, one connected to the index and middle fingers and the other connected to the ring and pinky fingers. Two exterior 'engage' buttons located on the fanny pack holding all our electrical components trigger the motors and cause the strings to reel in on spools, closing the hand. There are also two more buttons on the fanny pack that cause the spools to spin in the opposite direction, releasing each hand to its open state.

The open-loop design was chosen for our design as it was straightforward to implement. Concerns did arise with the open-loop design, such as the possibility of excessive and dangerous heat load generation potentially deteriorating the life of the motors. We addressed these by adequately ventilating the motor casing and also implementing the thumb strap. The thumb strap provided an additional force to close or grip the object, which meant less power would need to come from the motors themselves, thus reducing the possible deterioration.

The Arduino code attached in Appendix H began by setting up the motors and the four buttons to control the motors by assigning the respective input and output pins. The bulk of the code used if and while loops to create the desired motor movement based on the button being pressed. The same Arduino code controlled both hands, and thus the code encompassed all four buttons and all four motors. Another key feature of the code was speed control. During testing, we observed that the motors were spinning too fast to be controlled by Bill, leading to potential hazards. We implemented speed control using pulse-width modulation, which reduces the average power delivered by an electrical signal. The values of the pulse-width modulation vary from 0 to 255 and could be adjusted accordingly in the code to create a manageable pull-in and release speed.

5.4 Final Assembly

Once the entire glove was sewn together and all electrical components soldered, the final step was to attach the motors and spools and size the fishing wire and tracks. The images in Figure 31 below show the process of attaching the casing to the completed glove. At this point, we cut the tracks down to size to precisely reach the casing without much slack. The casing is attached to the glove by Velcro to allow Bill (or someone helping him) to lift the casing and put a plastic bag around it to protect the motors while the glove gets hand washed. The fishing wire enters the casing through individual holes on the front of the casing, as seen in the right image in Figure 31.



Figure 31. Attaching the Motor Casing and Sizing the Tracks

Attaching the fishing wire to the spools was a critical step of the final assembly. The fishing wire had to be cut to the proper length to prevent the fishing wire from being over-released. If the fishing wires were too long, Bill would be able to press the release button for longer, loosen this fishing wire on the spools, and increase the possibility of the wires getting tangled around each other or jumping over different parts of the spool. We cut the wires down to the exact length needed for full extension of the hand, so if Bill presses the release button for too long, the cables will switch directions and begin to tighten his hand again. This design makes it easy to know when the wires are fully unspooled, and Bill can make sure he is allowing his hand to extend completely.

The fishing wire also had to be threaded around rods that we placed inside the casing. The rods force the fishing wire to wrap around their designated part of the spool. These rods and how the fishing wire is threaded around them can be found below in Figure 32. There are also rods through the front of the casing that enter the spools and keep them around a center axis in the casing. After the cables were threaded, the middle lid was placed on, followed by the final top lid (see the middle images in Figure 32). Next, the rods were super glued in place from the outside, and the tracks were superglued and hot glued to the outside of the casing to prevent the track fabric from fraying. Finally, the casing was screwed together, and a small piece of Velcro was placed on top, surrounded by neoprene which gave the casing a soft exterior. There were slots cut in the neoprene to keep open the air holes above the motors for heat dissipation. We placed less Velcro on the top of the casing than the bottom so that when Bill takes off his glove, the casing stays attached by the bottom, allowing the wrist strap to come off the top.

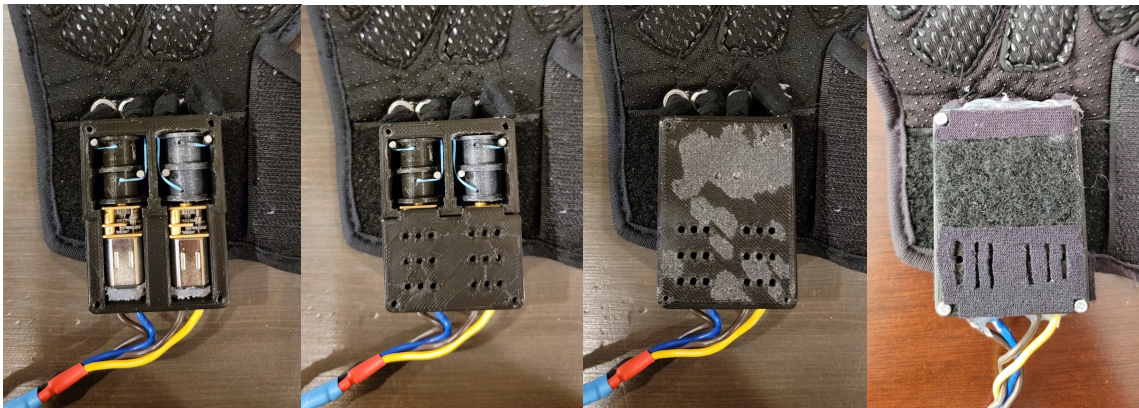


Figure 32. Final Motor Casing Assembly Process

5.5 Test Descriptions and Specification Verification Checklist

Our design verification involved conducting tests during Winter and Spring quarters to confirm that different components of our design worked along the way and to ensure the final design satisfied all of our engineering requirements. below is a summarized table of the tests we completed and when they were conducted. The numbers in parentheses represent the engineering

requirement that the test satisfied. The complete test plan with the detailed descriptions, type of test, and results of the tests completed is in Appendix F.

Table 4. Summary of Completed Tests

Test Number	Test Description	Finish Date	Corresponding Engineering Requirement(s)
1	General Cable Concept Works	1/29/21	(2) Finger Control (10) Range of Motion for Each Finger
2	Force needed to bring in fingers (using a hanging scale)	2/2/21	(2) Finger Control
3	Compare Various Grip Tapes and Evaluate Grip Effectiveness	2/16/21	(3) Grip Strength
4a	Test if Servo Motor Turns Spools and Collects Cables	2/23/21	Other: Mechanics Test
4b	Test if Gearmotors Turn Spools and Collect Cables	4/11/21	Other: Mechanics Test
5	Test Motor Driver Functionality	4/27/21	Other: Electronics Test
6	Test Button Functionality	5/19/21	Other: Electronics Test
7	Test Force needed to Overcome Friction of Glove	5/26/21	(3) Grip Strength
8	Touch Screen Compliant Test	5/26/21	(5) Touch Screen Compliant
9	Test if Glove Deteriorates after Hand Washing	5/27/21	(11) Washable Glove
10	Test Number of Steps to Put on Device	5/30/21	(7) Number of Steps Required to Put on Device
11	Test Bending of Left Pinky Finger with Device On	5/30/21	(8) Bending of Left Pinky Finger
12	Test Grip Strength with Device On	5/30/21	(3) Grip Strength
13	Test Diameter Limits of Items that Can Be Held	5/30/21	(4) Hold Items of a Certain Diameter with One Hand
14	Final Device Weight Test	5/30/21	(1) Device Weight Limit
15	Device Comfort	5/31/21	(9) Comfort

The first test we conducted was a test of our general cable concept. This test was described in our Proof-of-Concept Analysis and Testing section. We verified that the cable design could bring the fingers into an effective grip position to hold the items within the diameter range specification with this test. Additionally, we were able to test out different materials. We discovered that fishing wire is ideal for the cables and ruled out resin as a possible final material for the rings due to the undesired rigidity. After running more tests on the fishing wire, we found that the braided fishing wire specifically was more flexible and durable for our final design.

After confirming that the cable concept worked, we needed to find the force required to pull the cables to get the hand into a tight grip position. This revealed what amount of force our motors and cable needed to support. To do this, we used a hanging spring scale connected to the end of the fishing wire cables on the hand. We tested the force required to bring in each finger individually, the fingers in pairs, and all of the fingers together. We found that each finger required about one pound to close on its own, but the total force needed to close the hand decreased when we grouped the fingers. This result was expected as bringing in one of the fingers naturally pulls those nearest to it in as well. Therefore, grouping them is most effective. It took between two and two and a half pounds to close the whole hand when any grouping was utilized, so this was the force we needed our motors to supply. The exact results are detailed below in Table 5.

Table 5. Finger Force Measurements

Grouping	Finger(s)	Force Required (Ib_f)
Individual Fingers	Thumb	1.0
	Index	1.2
	Middle	1.2
	Ring	1.0
	Pinky	0.9
Groups of Two	Index and Middle	1.4
	Ring and Pinky	1.1
All Together	All	2.2

Our design incorporated grip tape to create friction between the glove and the item in-hand. The tape helped decrease the grip strength required for Bill to pick things up and reduced the possibility of them slipping out of his hand. We ordered various grip tapes from 3M to test which product was the most effective. The 3M grip tape is most effective when used against itself. For our purposes, we added grip tape on the glove, and asked that Bill place grip tape on the objects

he uses most commonly. We did not intend for everything in Bill's house to have this grip tape on it, but we wanted it on his go-to items, like a favorite glass or mug. One of the grip tapes we purchased came in sheet form (as seen in Figure 33 below), and the others in narrow rolls of tape. We tested the different grip tapes against the GM631 (sheet form) to guarantee that the tape was making complete contact during testing. We refer to the tapes by their respective colors for simplicity; however, the official names are also displayed in the image below. We used a hydro flask water bottle as a weight reference and placed a small piece of grip tape on the bottom of the bottle. Please note that the tapes' prefixes GM and TB are interchangeable.

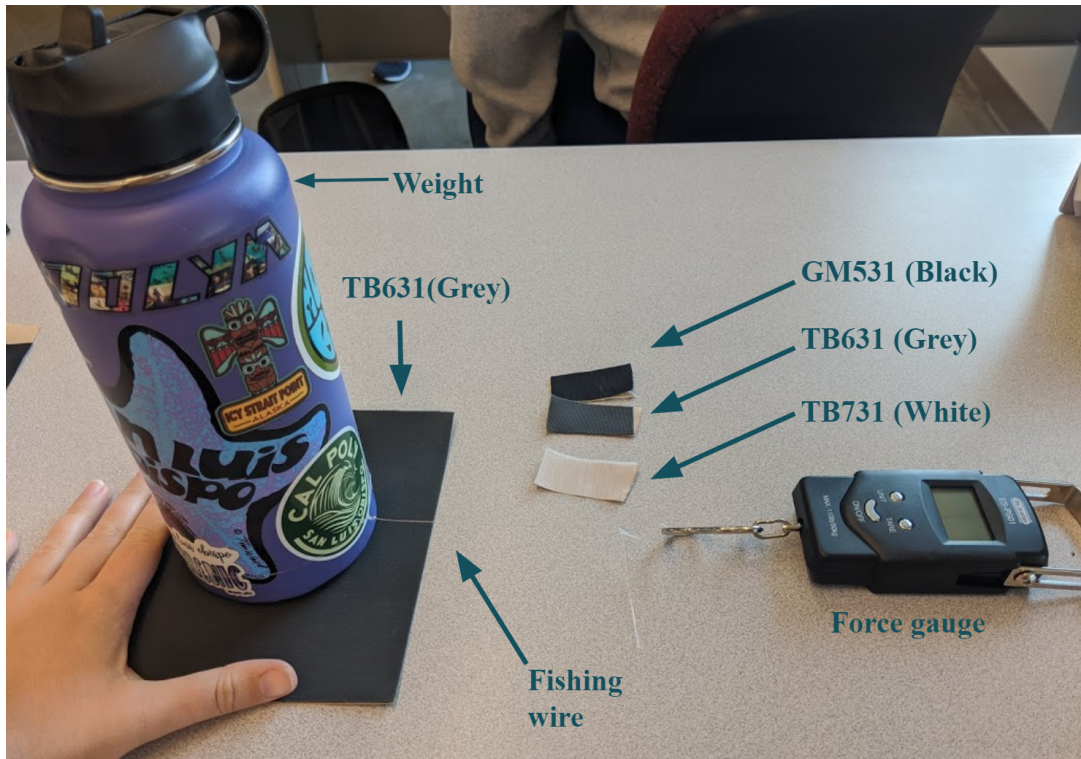


Figure 33. Grip Tape Test Setup

We recorded the amount of force it took to move the bottle along the GM631 sheet. The average results are summarized in Table 6 below, and the full results are in Appendix G. From this experiment, we opted to use the gray tape on the gloves as it was the most flexible, and asked bill to use the black tape on his everyday items.

Table 6. Grip Material Friction Test

Base Tape	Top Tape	Average Force Required to Initiate Movement
Grey	Grey	2.644 lbs.
Grey	Black	3.04 lbs.
Grey	White	2.956 lbs.

We conducted the following test to verify that our servo motors would collect the cables as they spin. We wanted to make sure that the servo motors functioned as expected and could supply the amount of force that we need to pull in the fingers. The servo motors came with various attachments, as shown in Figure 34 below. We 3D printed our spool attachment later on, but for this test, we used the circular attachment that the servo came with, allowing us to easily attach the fishing wire to the servo for testing purposes.

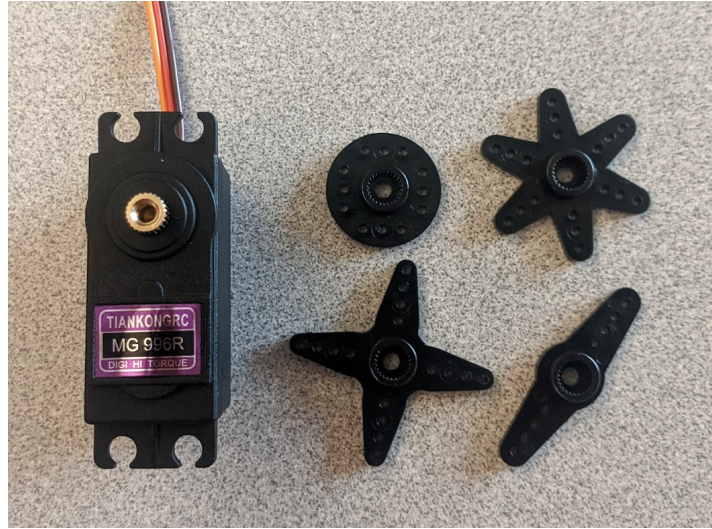


Figure 34. Servo Attachment Pieces

To test the force that the servo motor can supply, we tied the fishing wire to the circular attachment on the servo and connected the fishing wire to a force gauge (see Figure 35 below). We held the gauge and servo in position and ran the servo motor to observe the servo motor's force created by spinning. To conduct this test, we created a simple code in the Arduino app to run the servo (see Figure 36 below). After running this test a few times, we found that the force a single servo can create is roughly 1.67 pounds. This force meets our requirement as we needed about 2.2 pounds total force with two servo motors.

While the servo motor met our force requirement, we found that the rotation was limited to 180 degrees, limiting the flexibility we could have in sizing our 3D printed spools. With a maximum rotation of 180 degrees, the radius of the spool would have to be very large to achieve the desired linear displacement of the cables to pull the fingers in. As a result of this test, we decided to incorporate small gear motors with infinite rotation into our design to regain that flexibility in spool sizing and reduce space.

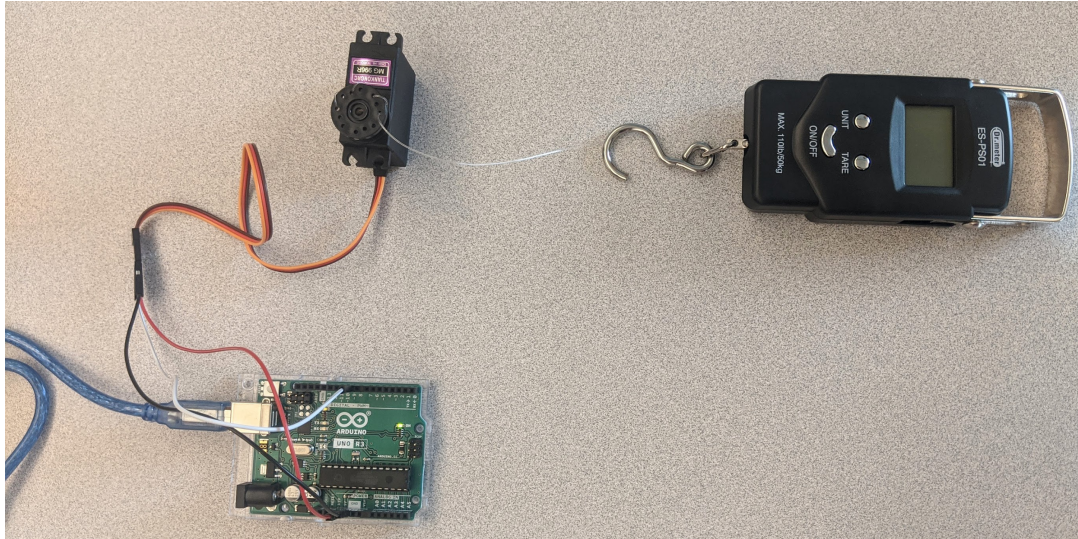


Figure 35. Servo Motor Force Test Setup

```
servo_test_2 §  
#include <Servo.h>  
Servo name_servo;  
  
int servo_position = 0; // initial servo position at 0 degrees  
  
void setup() {  
  // put your setup code here, to run once:  
  name_servo.attach(9); // servo is attached to pin 9  
}  
  
void loop() {  
  // put your main code here, to run repeatedly:  
  name_servo.write(180); // turn servo 180 degrees  
}
```

Figure 36. Servo Test Code

Once we decided to switch to gear motors, we ordered them and tested their functionality. Figure 37 shows our testing setup. We used an available battery box to substitute for a motor casing that we would make after verifying the gearmotors worked for our purposes. We tested the gearmotors by plugging them into the pins in the Arduino. We did not require code to test the motors for this initial testing, as they automatically spin once plugged into the voltage output.

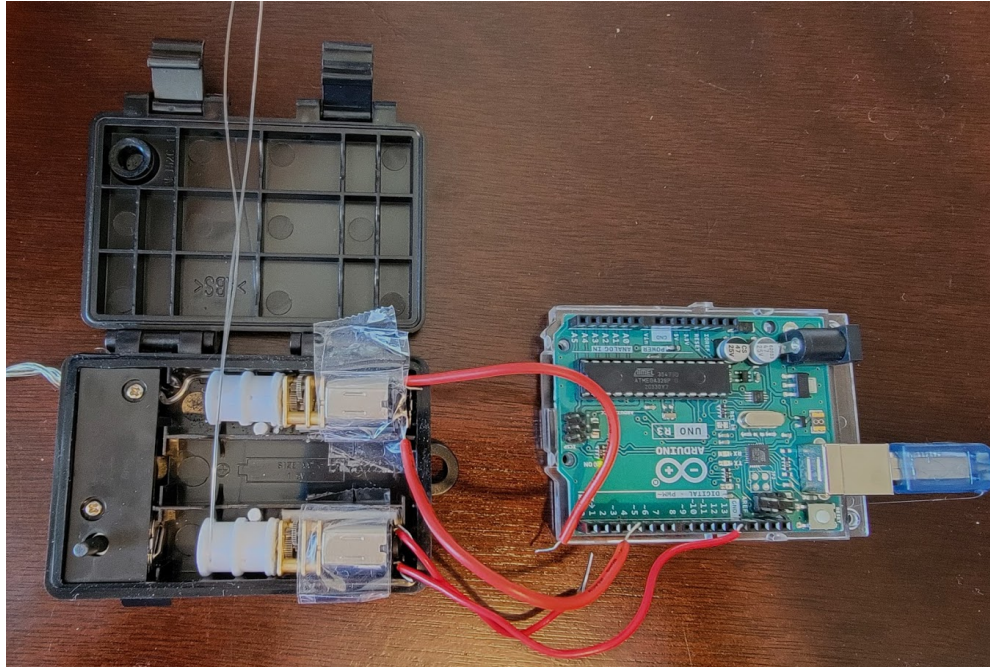


Figure 37. Gearmotor Functionality Test Motor and Arduino Setup

We hooked fishing wire up to the spools and connected them to finger caps we made to test if the motors would provide enough force to bring in the fingers. Our testing showed that the motors could bring in the fingers (as shown in Figure 38 below), but they did have some problems with stalling out. After some research, we discovered that Arduinos have a relatively low output current, and the motors needed a higher current to operate at their full ability. To solve this problem, we needed to buy a motor driver.

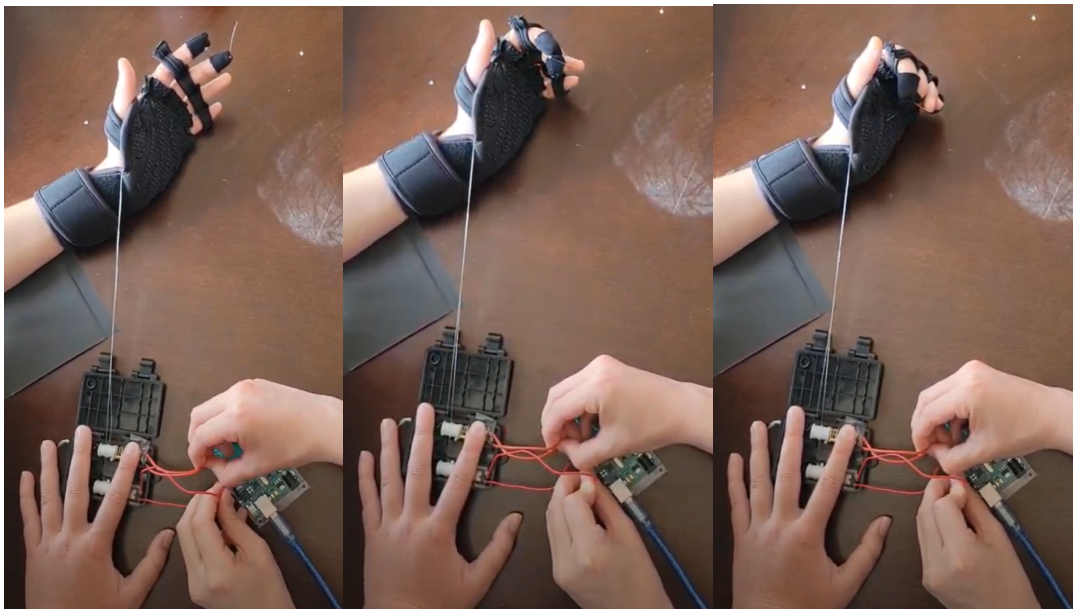


Figure 38. Gearmotor Functionality Test Results

After doing online research, we ended up purchasing the L298N Motor driver to test with our gearmotors. We created a motor casing that would fit the motor driver and 3D print it for testing, as seen in Figure 39. To test the motor driver's functionality, we had to hook it up to the gearmotors and a 6 Volt battery source rather than the Arduino. Doing this, we could quickly see and hear the motor power ramp-up. The motors spun faster and louder and did not stall when we hooked up the motors to our glove prototype.

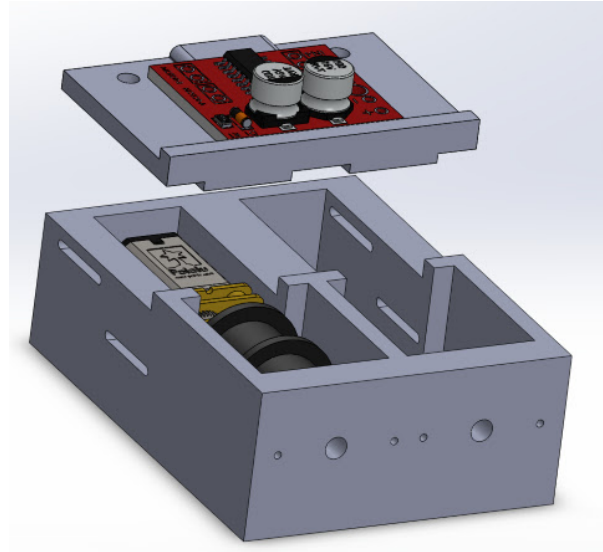


Figure 39. Motor and Spool Casing with Motor Driver

The last electrical test we needed to do was testing the functionality of the buttons. We had to solder all of our components together and write an Arduino program for the buttons. None of us are Electrical Engineering Majors, so we sought out help from Electrical Engineering Professor Chuck Bland to make sure our electronics would be safely and reliably constructed. We used some tester buttons to write the code before connecting everything to the final fanny pack. Figure 40 shows our testing setup. After spending sufficient time testing variations in the code, we wrote the final code, allowing the motors for each hand to be spun to grip and release. We decided on having four buttons, two for each hand.

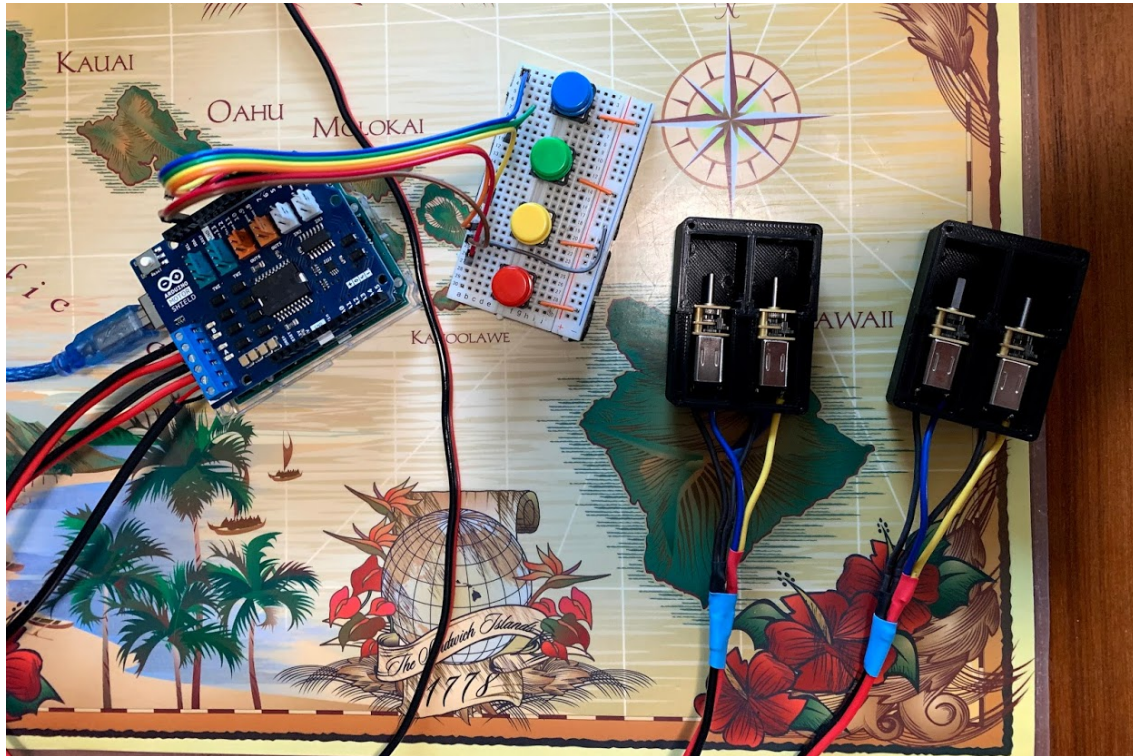


Figure 40. Button Testing Setup

After completing the trail runs with the testing buttons, we soldered everything to the final fanny pack and buttons. Unfortunately, two of the buttons we purchased were faulty, and we needed to buy higher-quality buttons. After purchasing the new buttons, we tested their functionality and resoldered the components. Figure 41 shows the process of detaching the old buttons and plexiglass and soldering in the new buttons, and assembling the new plexiglass. The new buttons had a better tactical response. They also had an indented surface, which felt more comfortable on the finger.



Figure 41. Replacing the Buttons

The next thing we needed to accomplish was deciding on a final glove to alter and testing the friction force of the glove itself. Before deciding on the final glove, we sent Bill multiple glove options to try on. We sent him a 3M work glove, a weight-glove from Amazon, and a glove with a zipper, making it easier to put on. Once Bill received all the gloves, we had a Zoom call with him to see which was the easiest to put on and which was the most comfortable. We watched him put on each glove to see what worked best. He quickly put on the weight glove and found it comfortable, so we decided to move forward with it. Once we decided on a glove, we tested it similarly to how we tested the grip tapes. We put it on the table with a weight on it, and we measured the force it took to get the glove to start slipping on the table. We used the same force gauge we had been using and the same fishing wire to attach the gauge to the glove. This test helped guarantee that our engineering requirement of allowing Bill to hold items of at least 2.5 pounds using one of his hands was met. Our test showed that the weight glove was able to hold up to a force of 1.2 -1.5 pounds which passed our requirement of withstanding a minimum of one pound of force. The friction provided by the gripping materials in conjunction with the grip force provided by the motors is what allowed us to meet that weight constraint.

Another aspect of the glove is that it needed to be able to be hand washed. If Bill uses the glove for long periods, it may get sweaty or dirty, and it will need to be washed. We purchased washable gloves and made sure everything we added to the gloves was washable. We tested this ourselves by hand washing the gloves and made sure they did not stretch, tear, or change in any other way. From our test, the gloves proved to be hand washable. Additionally, we made the motor casing removable with Velcro so Bill, or whoever is washing the glove, can lift off the motor casing and close a Ziplock bag around it to protect it while the glove is washed.

Once we completed the device assembly, we tested the grip strength with the device. We initially were going to use a hand dynamometer to test how much grip strength we could achieve with the

device on, but the hand dynamometer did not work for this because of the way the glove works. The hand dynamometer requires a specific grip position that the glove cannot achieve, so we tested the grip strength another way. We used the glove to hold a large diameter item to test the grip strength and found the heaviest item we could lift. We were able to use the glove to hold a Hydro Flask full of water that in total weighed 3 lbs. This verified that the device pulls in the fingers tight enough to force the object to be held. We were looking for our device to supply 2.5 pounds or above, and we achieved that. Likely the device can also hold heavier items that have smaller diameters or are held a different way. For example, we expect grocery bags with over 3 lbs. of weight in them will be able to be held with the device because they are held with the hand in a downward position which does not rely on the thumb; the weakest part of the device since a motor does not control it.

One of our engineering requirements was to make sure the number of steps to put on the device was less than six. We tested this ourselves before sending the glove to Bill and found it takes four steps to put on the device. This test was straightforward. We laid out the gloves on a table and counted the number of steps required to put them on. We expect it to be the same number for Bill. We referenced how he put on the gloves during the Zoom meeting to mimic his motions as closely as possible. The steps we counted are listed in Table 7 below.

Table 7. Steps to Put on Glove

Step Number	Step Description
1	Put on Fanny Pack
2	Connect Wires from Glove to Fanny Pack
3	Slide Hand in Glove
4	Wrap Wrist Strap

After testing the number of steps it took for us to put on the glove, we tested the minimum and maximum diameter that could be gripped with the device. This involved us picking up items with a range of diameters and recording the smallest and largest we were successfully able to pick up. We considered an item successfully held if we could pick it up and hold it for 1 minute without slippage or any other problems that affect the ability to use the item in question. Because of the thumb strap that we added to the glove, we could hold smaller items than with the previously limited mobility of the thumb. We were able to hold items that ranged in diameters between 0.25 and 4.5 inches. Figure 42 shows an example of holding a glass with the device. It is worth noting that with items over 3.5 inches, two clips are needed at the thumb to keep the thumb strap in place. However, items larger than 3.5 inches in diameter are uncommon for typical household items, so we do not foresee Bill having to add the second clip frequently. For this purpose and the possibility of a clip breaking in the future, we provided Bill with extra clips.



Figure 42. Device Being Used to Hold a Glass

To accommodate Bill's pain from bending his left pinky finger down, we did not attach the left pinky to a gearmotor. As the left ring finger gets pulled in by its gearmotor, the left pinky naturally follows part-way. To verify that it does not bring the pinky finger to a painful position, we put on the device and inspected how far the pinky finger came in when the left-hand device was used. We were looking for the pinky to bend no more than 90 degrees in either of the joints on the finger. The device passed this test even with the pinky finger hooked up to a motor. From this test result, we decided to go forward with hooking the left pinky up to a cable because it will assist his grip strength without creating any pain.

We had set an engineering requirement for the device's weight (on each hand) to be under 2.5 pounds. We tested this by weighing each glove on a scale and found them to be 0.3 pounds each, which is below our original expectation. We were able to make the gloves much lighter by moving the battery and other electrical components to a fanny pack that Bill will wear. This makes the device more comfortable and more accessible for Bill to use.

Since Bill uses an iPad, we wanted to make sure that the pad of his index finger was touch screen compliant. We thought we would have to test this because we were expecting to have some type of touch-sensitive material on his fingertips, but instead, we could leave the finger caps open enough to be used on his iPad.

To verify the comfort of the device, we tested it ourselves and had others that we know who have hands similarly sized to Bill test it. We received positive feedback about the comfort of the glove and believe Bill will feel the same. We asked each person about the comfort in each different area, including the hand, wrist, waist, and fingertips. Since we changed the design to softer

materials than we initially were going to use, the device's comfort was much higher than initially expected.

At this point in the process, our device was ready to be sent to Bill. We documented several tests that Bill can do himself if he wants to see how much the device helps him. We did not conduct these tests with Bill because we would have needed to send the device to Bill significantly earlier since he is in Park City, Utah, and we are in San Luis Obispo, California. We decided to use the last few weeks of our Senior Project to continue improving the device rather than shipping it to him early and conducting the tests virtually. Below are the tests Bill can conduct to compare his ability to do tasks with the device versus without it.

One test Bill can use to see how much the device helps him is a Hand Function Test. He can use a combination of the Jebsen-Taylor and the Sollerman Hand Function Tests, two standard occupational therapy tests. The Jebsen-Taylor test has seven sections which are shown in Table 8 below [8]. The Jebsen-Taylor test could be conducted by timing each task in seconds and comparing the time with and without the device, looking to see an improvement in the time required to complete each task.

Table 8. Jebsen-Taylor OT Test

Jebsen-Taylor Occupational Therapy Test		
Test Number	Subset	Task
1	Writing	Printing a 24-letter, third grade reading difficulty sentence
2	Stimulated Page-turning	Turning over 3x5-inch cards
3	Lifting Small Objects	Picking up small, common objects (pennies, paper clips, etc.) and placing them in a container
4	Stacking	Stacking checkers
5	Simulated Feeding	Using a spoon to scoop beans into a can
6	Moving Large Objects	Moving large empty cans
5	Lifting Large	Moving large, weighted (1 lb.) cans

The Sollerman Hand Function Test aims to test different hand grips [9]. The varying hand grips are tested by performing different actions such as turning a key in a lock, pouring water from a cup, etc. The user's performance is then ranked on a scale of 0-4. The different grips and the scale breakdown are shown in Figure 43 below. Specific tasks correspond to different grips, so Bill can use ones that are tasks he would like to perform with his device. If he wants to use this

test, he will conduct the tests with and without the device to ensure the device improves his ability to perform the desired tasks.

Sollerman Hand Function Test Ranking	
Score	Performance
0	Could not carry out the task
1	Task partially performed within 60 seconds
2	Task completed, but with great difficulty. The task was not carried out with the prescribed hand-grip, or the task was not completed within 40 seconds but within 60 seconds
3	Task completed, but with slight difficulty, or the task was carried out with the prescribed hand-grip but with slight divergence from normal, or the task was not completed within 20 seconds but within 40 seconds
4	The task was carried out without any difficulty within 20 seconds and with the prescribed hand-grip of normal quality









 1. Pulp Pinch	 5. Diagonal Volar Grip
 2. Lateral Pinch	 6. Transverse Volar Grip
 3. Tripod Pinch	 7. Spherical Volar Grip
 4. Five-Finger Pinch	 8. Extension Grip

Figure 43. Sollerman Hand Function Test Grips and Ranking

6 CONCLUSIONS AND RECOMMENDATIONS

Overall, we successfully created an assistive device to help Bill grip and hold various everyday objects. Through many iterations and testing, we met many of the customer requirements we determined at the beginning of the year. For example, with our final device, Bill will use both hands to grip and hold objects up to 3 lbs. per hand. The gloves themselves are very light and only weigh about 0.3 lbs. each. Once we moved many of the electrical components to be housed in the fanny pack, it was much easier to cut down the weight of the components on Bill's hands. The final gloves are also touch screen compliant and are very flexible and comfortable. Because of this, the gloves will not cause Bill's fingers to bend painfully.

Due to the limitation of Bill living in Utah, we were not able to work with him directly when manufacturing the glove. Instead, we used molds of his hands to size the gloves during construction. Another limitation we encountered was our lack of knowledge regarding electrical systems. We were fortunate enough to work with Professor Chuck Bland for much of the electrical component installation. This helped us construct the electrical parts of the device much more reliably and efficiently.

In the future, we would recommend looking into more solutions for the thumb. The thumb does not move like the rest of the fingers and goes in varying positions to grip different objects. If the thumb is to be used normally, a much more complex design is required, which would call for more experimentation and testing. Additionally, we think this design could be improved and made to fit other customers if a professional tailor was brought in to improve the sewing and potentially make sewing patterns for future use. The electrical components could also be iterated and improved further, possibly using more motors to add grip strength and independently control each finger. In addition, the electrical components could be condensed in size and placed closer to the hands to eliminate the long wires extending from the fanny pack to the gloves.

APPENDIX

Appendix A - References

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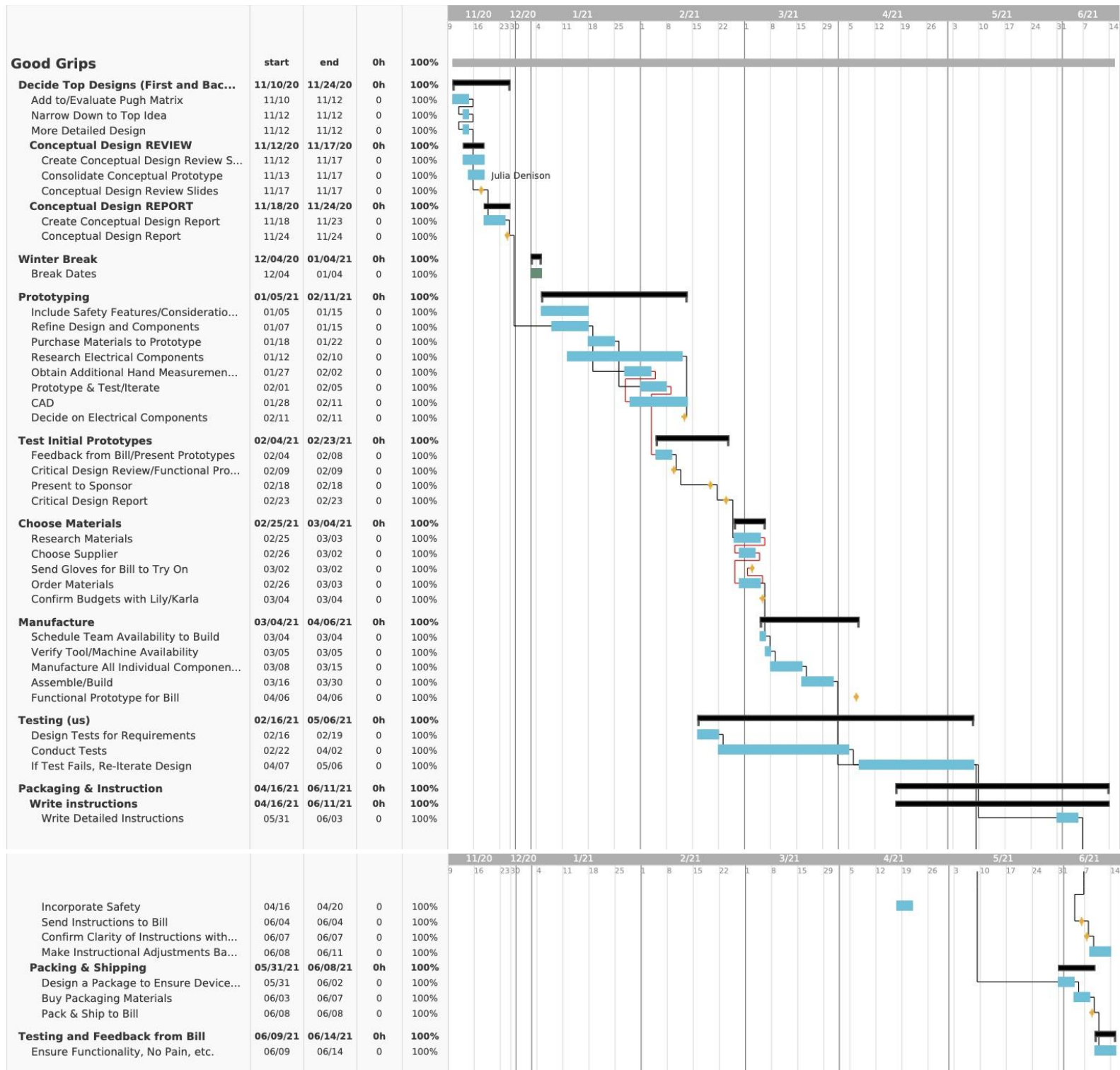
Appendix B - QFD

		Engineering Requirements (HOWS)																	Benchmarks		
		Weighting (1 to 5)	Weight Limit (2 lbs max)	Helps control all 5 fingers on both hands	Holds items of 0.25"-5" diameter	Index Finger Touch Screen Compliant	Device shall allow user to support at least 5 lbs with both hands together	<5 steps to put on and able to put on	Device will not allow left pinky finger to bend more than 90 (deg)	Soft material, rounded edges, and cushioned	Allows independent movement of each finger (at least 90 deg per finger segment)	Water resistant	Device can be put on with alterante hand	Washable inner piece					Active Hands	Adaptive Silverware Handles	Flexo Glove
Customer Requirements (Step #2)	Customer (Step #1) Requirements (Whats)																				
	Something for BOTH hands	5	9																9	9	9
	Help him hold: silverware	4		9						3									9	9	9
	pen/pencil	5		9						3									9	9	9
	glass	4		9						3									9	-	9
	mug	4		9						3									9	-	9
	remote	4		3															1	-	9
	pan	3		3		3													1	-	3
	cooking things (bags of flour/sugar) (want)																				
	open jars (want)	1		3															1	-	1
	Help him squeeze a toothpaste bottle (controlled) (want)	2		3															1	-	9
	Be able to hold 3-5 lbs (want)	3				9													-	-	1
	Lightweight (he can only hold 3-5lbs)	5	9																9	9	9
	Easy to put on himself (want not need)	1						9					9						9	9	-
	Use in the shower (want not need)	1										9		9					9	9	-
	Won't injure/scratch him if he falls while he has it on	3								3									9	1	-
	Still helpful if his index finger & thumb control worsens	3		3															3	1	9
	He uses an iPad a lot so his index finger tip needs to be uncovered (heat touch)	2				9													-	9	-
Avoid pain for his left pinky finger. (it hurts when it's bent more than ~90 degrees)	3							9										-	9	3	

Appendix C - Bill of Materials

No.	Material/Component	Unit	Qty.	Description	Manufacturer	Vendor	Part Number
1	Fit Active Sports Gloves, Men's XL	Pair	2	Glove	Fit Active Sports	Amazon	B00XM0MA2Q
2	600 Denier Nylon with Polyurethane Coating	in ²	12	Finger Caps	N/A	Quality Fabric Supply	
3	Gripping Material 631 - Gray Grip Tape	in ²	8	Gipping Material	3M	RS Hughes	TB631
4	Neoprene Sponge Foam Rubber Sheet Rolls	in ²	20	Inner Padding	Lazy Dog Warehouse	Amazon	LDW218
5	Hollow Ace Spliceable Braided Line Blue	Yards	100	Cables	Power Pro	Tackle Warehouse	B005ADORGK
6	Spools	Unit	4	Spool	Innovation Sandbox	Good Grips	462-01
7	Sticky Back Tape Roll with Adhesive (3/4in Width)	in	4	Arm Strap	Velcro	Amazon	90975W
8	Motor Case	Unit	2	Casing for Electronics	Innovation Sandbox	Good Grips	461-01
9	Pololu 6V Micro Metal Gear Motors	Unit	4	Motors	Polulu	Polulu	TBD
10	Arduino Uno	Unit	1	Microcontroller	Arduino	Arduino	A000066
11	Anker PowerCore 26800 Portable Charger	Unit	1	Battery	Anker	Amazon	A1277
12	Arduino Motor Shield	Unit	2	Motor Shield	Arduino	Arduino	A000079
13	Rainbow Ribbon Wire	in	6	Wire	Coast Electronics	Coast Electronics	
14	12-guage wire	ft	6	Wire	Coast Electronics	Coast Electronics	
15	Polyester Tracks	Unit	8	Tracks	Good Grips	Good Grips	
16	Gikfun Screw Shield Expansion Board	Unit	1	Screw Shield Expansion Board	Gikfun	Amazon	
17	Fanny Pack	Unit	1	Fanny Pack for Electronics	Cotopaxi	REI	
18	.093" Plexiglass Sheet	Unit	2	Stability for Fanny Pack	Home Depot	Home Depot	
19	SPST Buttons	Unit	4	Buttons	Amazon	Amazon	
20	Grommets 3/16"	Unit	8	Grommets for cables	Michaels	Michaels	
21	Grommets 1/2"	Unit	2	Grommets for wire	Michaels	Michaels	

Appendix D - Gantt Chart



Appendix E - Safety Checklist**SENIOR PROJECT CONCEPTUAL DESIGN REVIEW HAZARD IDENTIFICATION CHECKLIST**

Y	N	
<input checked="" type="checkbox"/>	<input type="checkbox"/>	Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Can any part of the design undergo high accelerations/decelerations?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will the system have any large moving masses or large forces?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will the system produce a projectile?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Would it be possible for the system to fall under gravity creating injury?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will a user be exposed to overhanging weights as part of the design?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will the system have any sharp edges?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	Will all the electrical systems properly grounded?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will there be any explosive or flammable liquids, gases, dust fuel part of the system?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Can the system generate high levels of noise?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures ,etc...?
<input checked="" type="checkbox"/>	<input type="checkbox"/>	Will the system easier to use safely than unsafely?
<input type="checkbox"/>	<input checked="" type="checkbox"/>	Will there be any other potential hazards not listed above? If yes, please explain below?

Appendix F - Design Verification Plan and Report

DVP&R														
Report Date				Sponsor	Bill							REPORTING ENGINEER:		
TEST PLAN							TEST REPORT							
Item No	Specification or Clause Reference	Test Description	Detailed Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
							Quantity per hand	Type	Start date	Finish date	Test Result	Quantity Pass (both hands)	Quantity Fail	
1	Finger Control	General Cable Concept Works	1. Put on glove prototype 2. Individually pull strings (by hand) on each finger and inspect their motion 3. Pull all strings simultaneously (by hand) and verify by inspection the motion of the fingers and hand	Pulls all fingers into hand	All	CV	1	Early Prototype (not final materials)	1/29/21	1/29/21	Pass	2	0	Decrease Fishing wire thickness
2	Finger Control	Force needed to bring in fingers (use hanging scale)	1. Put on glove prototype without motors attached 2. Using a spring gauge, pull each string individually and monitor and record the peak force required to pull each finger from a fully open to fully closed position 3. Also, measure the force required to hold each finger in a closed position	< Servo Motor Limit	All	CV	5	Early Prototype (not final materials)	2/2/21	2/2/21	1. Individual Fingers: Thumb (1 lb), Index (1.15 lb), Middle (1.2 lb), Ring (1 lb), Pinky (0.9 lb) 2. Pairs: Index and middle (1.45 lb), ring and pinky (1.1 lb), all 5 (2.2 lb)	10	0	1. Max force to hold all fingers (2.5 lbs) 2. When fingers are pulled in groups or all together, the force is less than pulling them all in together.
3	Grip Tape Strength	Compare various grip tape samples and evaluate effectiveness of grip	1. Attach a small piece of grip tape to a heavy object (make sure you keep this size consistent with other grip tapes) 2. Place sheet of grip tape on the table 3. Attach fishing wire to heavy object and force gauge 4. Record force needed to move the object from its starting position 5. Record 5 times and average	greatest grip strength	All	CV	per material	material samples	2/16/21	2/16/21	1. Grey on Grey 2.64 lbf 2. Black on Grey 3.04 lbf 3. White on Grey 2.956 lbf	3	0	We will use the black when we can, and the grey when we want larger sheets (because the black comes in role form and the grey comes in sheets). We tested all against the grey since it is the only one that comes in a sheet rather than a role. Therefore we know the tape on the object is in contact with the same surface area of the sheet tape (rather than having to deal with if the tape is not perfectly aligned)
4a	Servo Motor Function	Test if servo motor effectively turns spools and collects cables	1. Hook up cables to servo motors and observe how cables spool or pull when attached 2. Inspect that the spooling can be continuous and smooth	Pass	All	CV	2	individual servo motors and cables	2/16/21	2/23/21	Pass. The servo can create about 1.67 pounds. All of the servos we purchased operate properly. The speed the servo moved is adjustable and we will use a slower speed than the default.	4	0	We force the servo can create will increase once we 3D print our own spool attachments to use. The spool attachments will have a larger radius than the attachments that came with the servo (larger radius = larger force).
4b	GearMotor Function	Test if gearmotors effectively turn spools and collect cables	1. Hook up cables to gearmotors and observe how cables spool or pull when attached 2. Inspect that the spooling can be continuous and smooth	Pass	All	CV	2	Individual gear motors and cables	3/30/21	4/11/21	Pass. The gear motors move continuously and very smooth. We need to purchase a motor driver because currently the Arduino does not output the necessary current to operate the gearmotors at full strength.	4	0	
5	Motor Driver Functionality	Test if the motor driver gives more current to the gearmotors and allows them to run at full power	1. Hook up cables to gearmotors 2. Wire the motor driver to the motors and 6V battery source 3. Run the motors and observe motor speed and power	Pass	All	CV	2	Individual gear motors and cables using the motor driver	4/20/21	4/27/21	Pass. It was easily visible and audible that the motors were operating at a higher power and speed then before. They could deal with significantly more resistance from us without stalling.	4	0	
6	Button Functionality	Test if the buttons work and find the best way to program them.	1. Hook up cables to gearmotors 2. Wire gear motors to Arduino with Motor Shield 3. Run some test programs to use the buttons 4. Write final coding and test button functionality	Pass	All	CV	2	Buttons (2 per side, a grip button and a release button)	5/4/21	5/19/21	2 Buttons passed, 2 buttons failed. We tested the code with other buttons and the coding was correct and worked how we wanted, but our buttons were faulty.	2	2	Need to order new, better quality buttons
7	Glove Friction	Test force needed to overcome friction of glove	1. Place gloves grip side down on the floor 2. Place a known weight on the gloves 3. Attach a string to the gloves and observe how much force it takes to get the glove to start moving	> 1 lb	All	DV	1	Prototype Materials (football gloves, 3M grip gloves)	5/11/21	5/26/21	1.2-1.5 lbs	2	0	
8	Touch screen compliant	Use touch screen with index finger	1. Put on device 2. Try to use our phone or iPad with the device on, ensuring that all functionality remains the same	Pass	All	DV	1	complete design	5/20/21	5/26/21	Pass	2	0	We ended up leaving his fingertips open making which means they are all touch compliant
9	Washable Glove	Test if glove can actually be washed and won't fall apart or shrink. We will need to be able to detach the electrical components and fishing wire to wash the glove normally.	1. Hand wash glove and inspect if the glove falls apart or changes size after wash	Pass	All	DV	1	single glove	5/20/21	5/27/21	Pass	2	0	Easily hand washed. Motor casing can be lifted off the glove and placed in a ziplock bag for protection.
10	# of steps required to put on	Inspect and count the number of individual motions required to get the glove from fully off to fully on (We do this)	1. Lay the device in front of us 2. Count number of steps to put the device on	6	All	DV	4	complete design	5/24/21	5/31/21	4	8	0	1. Put on Fanny Pack 2. Clip in Wires 3. Slip on Glove 4. Wrap wrist strap
11	Bending of left pinky finger	Measure the angle the pinky finger bends with device on	1. Put the device on 2. Inspect that the pinky finger on the left hand does not bend more than 90 degrees and is not accidentally being pulled in	< 90 degrees	All	DV	2	complete design	5/24/21	5/31/21	< 90 degrees	4	0	Even when attached to a motor the pinky does not bend over 90 degrees in any joint, therefore we are going to hook his left pinky up to a motor since we can assist grip strength painlessly.
12	Grip Strength with device on	Hand Dynamometer	1. Put on device 2. Use hand dynamometer to test how much grip strength we can achieve with the device on	> 2.5 lbs	All	DV	1	complete design	5/24/21	5/31/21	>3 lbs	2	0	We were unable to use the Hand Dynamometer for this test because the glove does not allow for the very specific grip the Hand Dynamometer needs to read, so indeed we tested this with items that we weighed.
13	Hold items of a certain diameter with one hand	Test diameter max and min that can be held	1. Put on device 2. Pick up items with different diameters and observe what the max and min values are for our device	0.25" - 4.5"	All	DV	1	complete design	5/24/21	5/31/21	Pass 0.25" - 4.5"	2	0	With larger items (>3.5") two clips are needed at the thumb for the thumb strap to stay in place.
14	Device Weight Limit	Weigh Final device with scale	1. Place device on scale and analyze result	<= 2 lbs (per hand)	All	DV	1	complete design	5/24/21	5/31/21	0.3 lb per hand	2	0	Weighed much less than we originally anticipated since we moved the battery and other electrical components to the fanny pack.
15	Device Comfort	Have people test the device for comfort before sending it to Bill	1. Have user put on device themselves (get a range of users, we will test it ourselves and we will have people test it who have hands similar to the size of Bills hands. 2. Ask them about the comfort in the hand, wrist, waist, and fingertips 3. Ask them about any changes they think would help	Pass	All	DV	1	complete design	5/24/21	5/31/21	Pass. Originally we got feedback that having the motors on thr back of the hand was uncomfortable because the wires pull at a tight angle that can be felt on the wrist. After correcting this, but moving the motors to the forearm side of the wrist, we got all positive feedback that the glove was comfortable in all areas.	2	0	

Appendix G - Grip Tape Testing

Base Tape	Top Tape	Force measurement (lbf)
grey	grey	2.72
		2.6
		2.7
		2.8
		2.4
	average	2.644
grey	black	3.12
		3.2
		2.9
		3
		2.98
	average	3.04
grey	white	3.07
		3.3
		2.7
		2.7
		3.01
	average	2.956

Appendix H - Arduino Code

```
#include <JC_Button.h> //https://github.com/JChristensen/JC_Button

const byte  BTN_ORG = 4;
const byte  BTN_YEL = 5;
const byte  BTN_GRN = 6;
const byte  BTN_BLU = 7;

const int   MOTOR_PIN_A  = 12;
const int   MOTOR_SPEED_A = 3;
const int   MOTOR_BRAKE_A = 9;

const int   MOTOR_PIN_B  = 13;
const int   MOTOR_SPEED_B = 11;
const int   MOTOR_BRAKE_B = 8;

const int   CW  = HIGH;
const int   CCW = LOW;

const int   OFF = 0;
const int   ON  = 1;

Button leftARelease(BTN_ORG); //Black button
Button leftAGrip(BTN_YEL);    //Red button
Button rightBRelease(BTN_GRN); //Black button
Button rightBGrip(BTN_BLU);   //Red button

void setup()
{
    Serial.begin(115200); // seial monitor initialized

    //setup buttons
    leftARelease.begin();
    leftAGrip.begin();
    rightBRelease.begin();
    rightBGrip.begin();

    // motor A pin assignment
    pinMode(MOTOR_PIN_A, OUTPUT);
    pinMode(MOTOR_SPEED_A, OUTPUT);
    pinMode(MOTOR_BRAKE_A, OUTPUT);

    // motor B pin assignment
    pinMode(MOTOR_PIN_B, OUTPUT);
    pinMode(MOTOR_SPEED_B, OUTPUT);
    pinMode(MOTOR_BRAKE_B, OUTPUT);

    brake('A', OFF); // release brake
    brake('B', OFF); // release brake
}
```

```
void loop()
{
  //read the status of all the buttons
  leftARelease.read();
  leftAGrip.read();
  rightBRelease.read();
  rightBGrip.read();

  if (leftARelease.isPressed())
  {
    //ORG button
    //start the motor
    moveMotor('A', CCW, 100);

    //wait for the button to be released
    while (!leftARelease.isReleased())
      leftARelease.read();

    //stop the motor
    moveMotor('A', CCW, 0);

    //go back to the top of the loop
    return;
  }

  if (leftAGrip.isPressed())
  {
    //YEL button
    //start the motor
    moveMotor('A', CW, 100);

    //wait for the button to be released
    while (!leftAGrip.isReleased())
      leftAGrip.read();

    //stop the motor
    moveMotor('A', CW, 0);

    //go back to the top of the loop
    return;
  }

  if (rightBRelease.isPressed())
  {
    //GRN button
    //start the motor
    moveMotor('B', CCW, 100);

    //wait for the button to be released
    while (!rightBRelease.isReleased())
```

```
        rightBRelease.read();

        //stop the motor
        moveMotor('B', CCW, 0);

        //go back to the top of the loop
        return;
    }

    if (rightBGrip.isPressed())
    {
        //BLU button
        //start the motor
        moveMotor('B', CW, 100);

        //wait for the button to be released
        while (!rightBGrip.isReleased())
            rightBGrip.read();

        //stop the motor
        moveMotor('B', CW, 0);

        //go back to the top of the loop
        return;
    }

} // loop end

/*
 * Written by Ahmad Shamshiri August 29 2018 at 20:59 in Ajax,
Ontario, Canada
 * moveMotor controls the motor
   @param motor is char A or B refering to motor A or B.
   @param dir is motor direction, CW or CCW
   @speed is PWM value between 0 to 255

   Example 1: to start moving motor A in CW direction with 135 PWM
value
   moveMotor('A', CW, 135);

   Example 2: to start moving motor B in CCW direction with 200 PWM
value
   moveMotor('B', CCW, 200);
 */

void moveMotor(char motor, int dir, int speed)
{
    int motorPin;
    int motorSpeedPin;
```

```
if(motor == 'A')
{
    motorPin      = MOTOR_PIN_A;
    motorSpeedPin = MOTOR_SPEED_A;
}
else
{
    motorPin      = MOTOR_PIN_B;
    motorSpeedPin = MOTOR_SPEED_B;
}

digitalWrite(motorPin, dir); // set direction for motor
analogWrite(motorSpeedPin, speed); // set speed of motor
}

/*
 * brake, stops the motor, or releases the brake
 * @param motor is character A or B
 * @param brk if 1 brake, if 0, release brake
 * example of usage:
 * brake('A', 1); // applies brake to motor A
 * brake('A', 0); // releases brake from motor A
 */
void brake(char motor, int brk)
{
    if(motor == 'A')
    {
        digitalWrite(MOTOR_BRAKE_A, brk); // brake
        delay(1000);
    }
    else
    {
        digitalWrite(MOTOR_BRAKE_B, brk); // brake
        delay(1000);
    }
}
```

Appendix I - Motor Casing SolidWorks Drawings